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THE EFFECT OF WEATHER AND CLIMATE ON THE SUCROSE CONTENT OF SUGARCANE.....*M. A. Lugo-López and B. G. Capó* 149

THE INFLUENCE OF POTASSIUM ON THE YIELD AND SUCROSE CONTENT OF SUGARCANE.....*George Samuels and Pablo Landrau, Jr.* 170

THE EFFECT OF DIFFERENTIAL SUGARCANE FERTILIZER TREATMENTS ON A COLOSO SILTY CLAY
George Samuels and Pablo Landrau, Jr. 179

IDENTIFICATION, OCCURRENCE, AND DISTRIBUTION OF STRAINS OF SUGARCANE MOSAIC IN PUERTO RICO.....*G. W. Bruehl* 188

RELATIONSHIP BETWEEN CHROMOSOME NUMBER AND STOMATA SIZE IN CERTAIN PINEAPPLE VARIETIES.....*Alicia R. de Hernández* 199

CONTROL OF FACTORS INCREASING THE PREWEANING MORTALITY OF SWINE IN PUERTO RICO.....*A. González-Chapel and Ismael Carlo* 205

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The Effect of Weather and Climate on the Sucrose Content of Sugarcane

M. A. Lugo-López and B. G. Capó[1]

INTRODUCTION

The importance of harvesting a sugarcane crop with a high sucrose content can hardly be overemphasized. High-sucrose canes mean more sugar per acre without increased cane tonnage which involves high labor costs in harvesting and processing. In a previous paper (17)[2] the possibility of increasing sucrose yields through the use of superior varieties was discussed. Data on the influence of fertilizers in this respect have also been presented (20). This paper reports data pointing to the significant influences of weather and climate on the sucrose content of sugarcane at harvesttime.

ANNUAL VARIATIONS IN SUCROSE CONTENT OF SUGARCANE

The effect of weather on the sucrose content of sugarcane may be evaluated, in part, by observing the variations in sucrose yields in any sugar-producing country from year to year. The same variety of cane grown with strictly the same agronomic practices will vary in sucrose content from one year to another, even when grown on the same soil.

These variations are largely the results of variations in weather. In 1931, Das (18), in Hawaii, wrote: "In spite of our best efforts the sucrose content of our cane varies from year to year due more to weather conditions than to any other single factor". Table 1 gives historical production data for sugarcane in Puerto Rico for the past 32 years. There have been large fluctuations in sucrose yields (available 96° sugar-percent-cane) from year to year. Extremely low values of 10.53, 10.70, 10.75, and 10.85 percent occurred in the early twenties and again in 1952. Canes of very high sucrose

[1] Associate Soil Scientist, and Associate Director for Research, respectively, Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P. R.

Thanks are due to Mr. I. Bangdiwala and Dr. G. Samuels for their cooperation in planning and conducting the study. Appreciation is also expressed to Dr. J. A. Bonnet who provided the necessary data from his long-time experiments at Río Piedras and Guánica.

[2] Numbers in parentheses refer to Literature Cited, p. 168–9.

TABLE 1.—*Historical production record of sugarcane in Puerto Rico for the period 1920-52*[1]

Crop year	Cane ground	96° sugar produced	Area in cane	Cane yield per acre	Sugar yield per acre	Sucrose yield
	Tons	*Tons*	*Acres*	*Tons*	*Tons*	*Percent-cane*
1920	4,512,000	485,000	240,000	18.8	2.02	10.75
1921	4,468,000	491,000	241,000	18.5	2.04	10.99
1922	3,651,000	406,000	244,000	15.0	1.66	11.12
1923	3,370,000	379,000	240,000	14.1	1.58	11.24
1924	4,253,000	448,000	237,000	18.0	1.89	10.53
1925	6,173,000	661,000	240,000	25.7	2.75	10.70
1926	5,436,000	606,000	243,000	22.4	2.49	11.15
1927	5,665,000	630,000	236,000	24.0	2.67	11.12
1928	6,405,000	752,000	238,000	26.9	3.16	11.73
1929	5,244,000	587,000	251,000	20.9	2.34	11.18
1930	7,199,000	872,000	254,000	28.3	3.43	12.12
1931	7,037,000	788,000	279,000	25.2	2.82	11.19
1932	8,418,000	992,000	294,000	28.6	3.37	11.79
1933	7,165,000	834,000	300,000	23.9	2.78	11.64
1934	9,076,000	1,114,000	300,000	30.2	3.71	12.27
1935	6,391,000	781,000	299,000	21.3	2.61	12.21
1936	7,592,000	926,000	300,000	25.3	3.09	12.19
1937	8,144,000	996,000	301,000	27.1	3.31	12.23
1938	8,800,000	1,077,000	301,000	29.3	3.58	12.24
1939	6,875,000	852,000	314,000	21.9	2.71	12.39
1940	8,795,000	1,019,000	303,000	29.0	3.36	11.58
1941	7,745,000	932,000	337,000	23.0	2.76	12.03
1942	10,010,000	1,148,000	338,000	29.6	3.40	11.46
1943	8,678,000	1,039,000	319,000	27.2	3.26	11.97
1944	5,602,000	724,000	313,000	17.9	2.31	12.91
1945	7,998,000	964,000	336,000	23.8	2.87	12.05
1946	7,539,000	909,000	352,000	21.4	2.58	12.06
1947	9,286,000	1,088,000	365,000	25.5	2.98	11.72
1948	9,541,000	1,108,000	369,000	25.8	3.00	11.62
1949	10,998,000	1,277,000	376,000	29.2	3.40	11.62
1950	10,614,000	1,286,000	382,000	27.8	3.37	12.12
1951	10,501,394	1,227,623	396,000	26.5	3.10	11.69
1952						10.85

[1] Information obtained from reports of the Association of Sugar Producers of Puerto Rico.

values such as 12.91 percent in 1944, and containing more than 12 percent were harvested in 1930, 1934, 1935, 1936, 1937, 1938, 1939, 1941, 1945, 1946, and 1950, as can be seen from table 1. The sucrose yields fell in between 11 and 12 percent for the rest of the period. From 1929 to 1930 there was an increase of 0.94 in sucrose-percent-cane, but an equivalent drop occurred during the following milling season. A similar increase occurred from 1943 to 1944. In 1950, the mean yield of sucrose-percent-cane was 12.12, but it

TABLE 2.—*Seasonal variation in mean sucrose-percent-cane for 4 varieties of sugarcane grown at Isabela Substation*[1]

Variety	Mean yield in sucrose-percent-cane for				Mean of the 4 crops
	Plant cane 1946–48	First ratoon 1948–49	Second ratoon 1949–50	Third ratoon 1950–51	
M. 28	13.63	11.68	12.87	12.02	12.55
P. O. J. 2878	13.01	10.67	11.81	10.52	11.50
P. R. 902	13.74	11.46	12.50	11.94	12.41
P. R. 905	13.78	11.55	12.27	12.18	12.45
Mean of all varieties	13.54	11.34	12.36	11.67	12.23
Least significant difference needed between varieties of same crop at:					
5-percent level	0.35	0.47	0.52	0.41	0.28
1-percent level	.48	.65	.71	.57	.36
Least significant difference needed between crops at:					
5-percent level	.44				
1-percent level	.66				

[1] Calculated from data presented in: Response of four sugarcane varieties to fertilizers during the Isabela Cycle, 1946–51, Pablo Landrau, Jr., and George Samuels, *J. Agr. Univ. P. R.* **38** (2) 83 1954.

dropped during the next 2 years to 10.85 in 1952, a loss of 1.27 sucrose-percent-cane.

In Table 2 an example is given of variations in the sucrose content of sugarcane from different harvests during a variety trial. In any one crop year, varieties P.R. 902, M. 28, and P.R. 905 (with exception of the second ratoon) outyielded P.O.J. 2878 in sucrose. However, these varieties displayed significant variations in sucrose content from one crop year to another. Table 2 shows that the 1946–48 crop had the highest sucrose content, whereas the 1948–49 and 1950–51 crops were lowest. The mean sucrose yield ran from a high of 13.54 for the 1946–48 crop season to a low of 11.34 for the 1948–49 season, a difference of 2.20 percent. This seasonal difference was much higher than any difference encountered between varieties.

SUCROSE CONTENT OF SUGARCANE

WHEN GROWN IN DIFFERENT CLIMATIC BELTS

Table 3 gives data on sucrose yields during the period 1947–52 for the various sugarcane-producing districts of Puerto Rico.[3] There is a variation

[3] The geographical distribution adopted by the Association of Sugar Producers of Puerto Rico was used. Hence, north includes the general area where the Río Llano,

TABLE 3.—*Mean sucrose yields (percent-cane) of sugarcane grown in 5 geographical districts of Puerto Rico during the period 1947-52*

Crop year	North	South	East	West	Interior	Mean
1947	11.42	12.09	11.27	11.91	11.76	11.69
1948	11.22	11.98	11.31	11.98	11.82	11.66
1949	11.35	12.18	10.96	11.71	11.55	11.55
1950	11.49	13.02	11.47	12.53	11.66	12.03
1951	11.43	12.06	11.03	12.18	11.47	11.63
1952	10.44	11.52	10.35	11.30	10.48	10.81
Mean	11.23	12.14	11.06	11.94	11.46	11.56

in sucrose due to year influences which can be attributed to variations in the weather. The highest production of sucrose was obtained in 1950 and the lowest in 1952.

Table 3 further shows that there are distinct differences in the sucrose concentrations of the cane obtained from the various geographical districts. Figure 1 shows these variations more clearly. Irrespective of yearly influences, the highest sucrose-yielding canes were harvested at the southern irrigated plantations where rainfall is very low the year around, but especially from December to May. Furthermore, the field-irrigation schedules usually provide for the "drying out" of the canes for some 45 to 60 days prior to harvest. At that time growth decreases and the ripening processes of the green-leaf millable cane are promoted.

The western region invariably produces canes higher in sucrose than the interior, northern, and eastern regions. In western Puerto Rico there is generally a marked dry season during the months corresponding to the sugarcane-harvesting season. In the other three geographical areas rainfall decreases during the harvesting season, but occasional rains of variable intensity are likely to occur which presumably hinder the ripening process and promote new vegetative growth. This type of weather is not uncommon at Río Piedras, Cayey, San Lorenzo, Humacao, Naguabo, and other areas in the northern, eastern, and interior districts.

Los Caños, Cambalache, Plazuela, Monserrate, San Vicente, Constancia-Toa, Juanita, Victoria, and Canóvanas sugar mills are located; while in the south the general area around the following mills is included: Guánica, San Francisco, Rufina, Mercedita, Constancia, Cortada, Aguirre, Machete, Lafayette, and Guamaní. East includes the area of the Fajardo, Pasto Viejo, El Ejemplo, and Roig sugar mills; west, that of the Coloso, Rochelaise, Eureka, and Igualdad; and interior refers to the area near the Plata, Soller, Santa Juana, Juncos, and Cayey mills. Any further mention in this article of the various climatic, geographic, or sugarcane-producing districts refers to the areas above described.

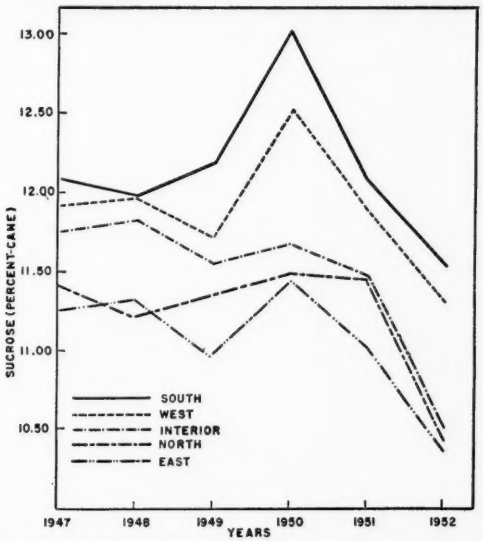

FIG. 1.—Sucrose yields of sugarcane in Puerto Rico for the 6-year period 1947-52, by geographic regions.

In the interior district, in spite of the relatively heavy rainfall occurring throughout the year, canes with richer juices are harvested than in the North and East. The interior is characterized by relatively low temperatures, especially during the nights which are conducive to decreased respiratory activity, and consequently to increased storage of sucrose.

AS RELATED TO RAINFALL

A plentiful supply of water is normally required for adequate plant growth as well as for the formation and translocation of sucrose. It has long been recognized that although total rainfall is of importance, its seasonal distribution must be considered also. As far back as 1898, Stubbs (22), working in Louisiana, recognized the detrimental effects of heavy rains during the ripening months: "Eighteen hundred and ninety-eight was notorious for excessively green cane. The rainfall, while not up to the normal for the year, was excessive during the fall months and carried the cane into the grinding season gorged with moisture and exceedingly immature."

Quintus (19) from Java reported:

> Sugarcane requires a fairly accentuated alternation of monsoons. It is necessary that a period of plentiful rain be succeeded by some months of dry weather, as other-

wise the cane is unable to attain full maturity, so that a large crop of cane is indeed gathered, but the percentage of sugar is so low that the profit is inconsiderable. Likewise, the time when the dry period commences is of importance; if it arrives too late, the cane does not ripen completely; and this is also the case if the dry weather sets in too early; when the cane, moreover, dies prematurely.

The researches of Jorgensen (14), Geerligs (12), Das (8, 9), Beauchamp (1), McDonald (18), Tengwall and Van der Zyl (23), Van Deventer (25), and Thiem (24), working under various conditions, all indicated that high sucrose yields are associated with abundant rainfall during the growing period and dry weather for a few months prior to harvesting. Prolonged droughts may be harmful also. The unfavorable effects of prolonged droughts are best summarized by Geerligs (12): "Cane having had an abnormal growth owing to drought often ripens very rapidly; the ripening process proves to be very short, the cane soon becomes over ripe and loses in sugar content."

Figure 2 shows the fluctuations in sucrose content of the cane harvested in Puerto Rico for the past 32 years and the total rainfall for the corresponding crop years. Since no direct rainfall measurements were available it was assumed for plotting the data that the crop year extended from April of a given year to March of the following year. This, of course, introduces

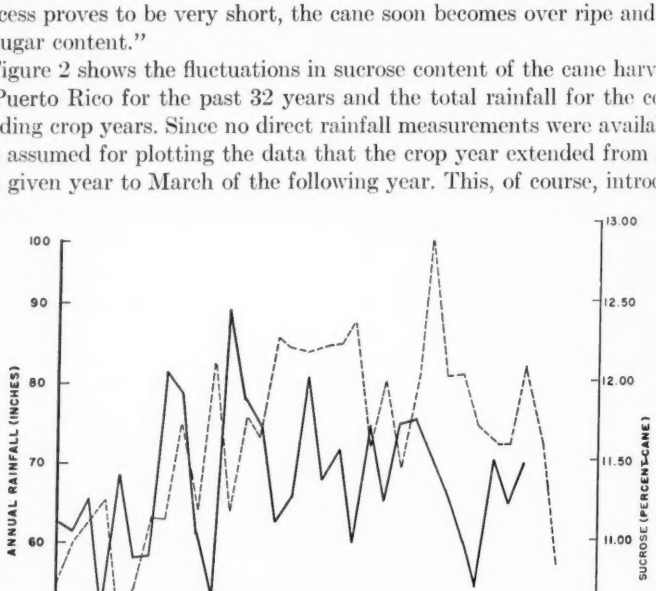

FIG. 2.—Sucrose yields in Puerto Rico as related to annual rainfall for the period 1920–52.

obvious errors since the cane was harvested anywhere from January to May or June; and March may not be necessarily typical of the whole season throughout the 32-year period.

In spite of obvious limitations the data indicate that variations in sucrose are generally in inverse relationship with variations in rainfall for the crop year. Thus, high sucrose yields were generally obtained in years when rainfall was least, while low-sucrose canes were usually harvested in years of high rainfall. The high peak in sucrose observed in 1944 cannot be explained wholly on a basis of decreased rainfall. In the previous year the import of fertilizers sharply decreased because of the war emergency. Cane and sugar yields decreased accordingly (table 1), but the sucrose concentration of the juices increased. The lack of sufficient nitrogen for that crop year may have resulted in reduced tonnage due to the production of canes of less succulence, but with more concentrated juices.

FUNCTIONAL RELATIONSHIPS AT VARIOUS PERIODS PRIOR TO HARVEST

The literature already cited indicates that excessive rainfall during the harvesting period is deterimental to the quality of cane juices. A study was conducted to determine the critical period at which rainfall would have maximum effect on the concentration of the juices.

Data covering a 10-year period (1939–49) were gathered from various specific commercial fields on several sugarcane estates in east-central Puerto Rico, a humid section. A large number of cases was studied to determine the correlation between sucrose content and rainfall at various periods prior to harvesting. Table 4 shows significant regression coefficients found in 20 fields at the various estates. It is evident from table 4 that sucrose contents are lowered in a considerable number of cases by increases in rainfall in the months approaching harvesttime. The last 3 months seem to be more decisive.

There is a distinct possibility that some other factor may to some extent mask the effect of rainfall on sucrose yields. Soil conditions may be of importance. At Colonia Esperanza satisfactory correlation was observed in four out of five fields studied. The predominant soils there belong to the Las Piedras and Juncos series, both well-drained soils of medium productivity derived from granitic and tuffaceous materials. Significant regressions were obtained at Santa Teresa in fields of alluvial soils, such as those of the Irurena and Josefa series where adequate drainage has been provided by open ditches, but none was observed in soils like those of the Reparada and Palmas Altas series which have high water tables. A significant regression was obtained at Río Grande between sucrose content and total rainfall 3 months prior to harvest only in a field of Juncos silt loam, but none in fields of Mabí clay. Similar results were obtained elsewhere.

TABLE 4.—*Regression coefficients between sucrose content (percent-cane) and total rainfall during 5 periods prior to harvesting on various estates in Puerto Rico*[1]

Estate	Field No.	Soil type	Variety	Number of years	Regression coefficient between sucrose and rainfall—				
					1 month before harvesting	2 months before harvesting	3 months before harvesting	4 months before harvesting	5 months before harvesting
Factoría	59	Múcara silty clay loam	P.O.J. 2878	6			−0.171**		
Esperanza	78	Las Piedras silty clay loam	do.	9					−0.149*
Do.	82	do.	do.	7		−0.155**		−0.179*	− .151*
Do.	17	do.	do.	10		− .396**			
Do.	21	Juncos silt loam	do.	10	−0.270*				
Preston	47	do.	do.	7				− .244*	
Mandry	78	Aguadilla loamy sand	do.	11	− .579*	− .422*			
Eugui	36	Cayaguá silt loam	P.R. 803	5	− .068*	− .043*			
Do.	9	do.	do.	7					− .063*
Río Grande	17	Juncos silt loam	B.H. 10/12	7			− .207*		
Buena Vista	71	do.	do.	6				− .190*	
Santa Teresa	2	Irurena clay	do.	10	− .290*	− .282**	− .186**	− .149*	
Do.	11	Irurena loam	do.	10	− .304*	− .247**	− .172**		
Do.	15	Josefa clay loam	do.	10	− .418*	− .245*	− .227*		
Miraflores	240	Toa loam	do.	7		− .331*		− .109*	
Do.	241	do.	do.	8			− .177*		
Santa Rosa	216	Coloso clay	do.	5			− .140*		
Do.	223	do.	do.	5			− .138*		
Doctores	2	Juncos silt loam	do.	5		− .555*			
Do.	10	Toa loam	do.	4		− .454*	− .327*		

[1] * = Significant value of the coefficient of regression; ** = highly significant value of the coefficient of regression.

TABLE 5.—*Relationship between the sucrose yield (percent-cane) of sugarcane and rainfall at various periods prior to harvest in selected areas of Puerto Rico*

Area	Cases (number)	Functional relationship[1]	Coefficient of determination	Correlation coefficient	F value[2]
Guánica	64	$Y = 12.76 - 0.2380\ X_1$	0.09	−0.31	6.74*
	64	$Y = 13.12 - .2028\ X_2$	.29	− .53	25.44**
	64	$Y = 13.41 - .1474\ X_3$	.50	− .70	62.36**
	64	$Y = 13.57 - .1080\ X_4$	.42	− .65	45.68**
	64	$Y = 13.64 - .0830\ X_5$	.23	− .48	19.07**
	64	$Y = 13.42 - .0556\ X_6$	.08	− .27	5.11*
Aguirre	122	$Y = 12.89 - .1662\ X_1$	.11	− .33	15.22**
	122	$Y = 13.30 - .1627\ X_2$	.28	− .53	47.96**
	122	$Y = 13.27 - .0933\ X_3$	.20	− .44	30.27**
	122	$Y = 13.65 - .0971\ X_4$	.28	− .53	48.01**
	122	$Y = 13.41 - .0575\ X_5$	.12	− .34	16.50**
	122	$Y = 13.70 - .0584\ X_6$	.15	− .39	18.54**
Boca Chica	57	$Y = 12.46 - .6042\ X_1$	.54	− .73	65.81**
	57	$Y = 12.55 - .3198\ X_2$	.35	− .58	29.30**
	57	$Y = 13.09 - .2642\ X_3$	.62	− .78	85.45**
	57	$Y = 13.22 - .1797\ X_4$	.65	− .80	103.87**
	57	$Y = 13.40 - .1404\ X_5$	.53	− .73	63.07**
	57	$Y = 13.58 - .1171\ X_6$	.35	− .59	30.01**
Mercedita	76	$Y = 11.79 - .0098\ X_1$	.001	− .03	.08**
	76	$Y = 12.07 - .0616\ X_2$	.10	− .32	8.70**
	76	$Y = 12.33 - .0720\ X_3$	.23	− .47	21.98**
	76	$Y = 11.93 - .0144\ X_4$	.01	− .14	.89**
	76	$Y = 12.71 - .0623\ X_5$	.23	− .47	21.80**
	76	$Y = 12.57 - .0418\ X_6$	.09	− .33	7.42**
Machete	145	$Y = 12.57 - .0225\ X_1$	.002	− .06	.42**
	145	$Y = 12.83 - .0760\ X_2$	.07	− .26	10.99**
	145	$Y = 13.36 - .1202\ X_3$	.28	− .53	56.52**
	145	$Y = 13.85 - .1253\ X_4$	.42	− .64	102.06**
	145	$Y = 14.16 - .1102\ X_5$	.37	− .61	84.76**
	145	$Y = 14.26 - .0903\ X_6$	.24	− .49	45.63**

[1] Y = Sucrose percentage to be estimated; X_1, X_2, X_3, X_4, X_5, and X_6 = rainfall during 1, 2, 3, 4, 5, and 6 months immediately prior to harvest, respectively.

[2] * = Regression is significant; ** = regression is highly significant.

Additional and more precise data were processed from five broad areas in the semiarid South where irrigation is indispensable if a crop of sugarcane is to be raised successfully. Information was obtained on sucrose yields for each month of the harvesting season and accurate rainfall records for each month of the crop year were gathered covering the period 1929–43. Table 5 shows the functional relationships worked out and gives coefficients of determination and correlation. Almost invariably a relatively large percent-

age of the variation in the sucrose content of the cane at harvesttime can be explained on basis of the total rainfall during 1 to 4 months immediately preceding harvest. The regression coefficients are all negative, indicative of decreases of sucrose with increases in rainfall in this critical period.

Estimates of the sucrose content of cane can be made by using a linear regression as a first approximation by means of the equation:

$Y = (\bar{Y} - b\bar{X}) + bX$, where

Y = sucrose percentage to be estimated

$\bar{Y}$ = mean sucrose content of cane for the period to the data of which the equation applies

b = regression coefficient

X = rainfall at a given period prior to harvest, and

$\bar{X}$ = mean rainfall for same period as X

Table 5 shows that 50 and 42 percent of the variability in sucrose yield at Guánica could be explained by taking as a basis the rainfall 3 and 4 months prior to harvest, respectively. Over 20 percent of the variation in sucrose yield at Aguirre could be explained on a basis of total rainfall either 2, 3, or 4 months before harvest. In the lands of the old Boca Chica mill near Ponce, more than half of the variability in sucrose yield could be explained on a basis of the rainfall 1 month before harvest. The rainfall 3 or 4 months prior to harvest could account for over 60 percent of the variability in sucrose yield.

Table 6 shows a comparison of measured sucrose yields at Boca Chica for a given time and estimated yields on basis of the rainfall 4 months prior to harvest. The deviations of the estimated from the observed values are rather small.

AS RELATED TO TEMPERATURE

The influence of temperature on the sucrose content of cane was recognized at an early date by Browne and Blouin (5) in Louisiana. The sucrose yields of the Louisiana 1903 and 1904 crops were strikingly different and the authors could attribute this only to the extreme differences in temperature between the two years. Deer (11) reported:

> In those places that have an uniformly high temperature and no cool season, an impure cane of low sugar content and high in reducing sugars is almost invariably harvested. In such a case there is an opportunity for continuous vegetative growth and the crop as it reaches the mill will consist of canes full of vegetative vigor.

Ishida and Sawasaki (13), in Formosa, found that a rise of 1°C, above normal during the ripening season decreased the sucrose content of cane by nearly 0.5 percent, while an equivalent fall in temperature induced increases in sucrose. Koenig (15, 16), in Mauritius, Van Deventer (25), in Java, and

TABLE 6.—*Comparison of actual sucrose yields at Boca Chica, P. R., and values calculated on a basis of total rainfall 4 months prior to harvest*

Date	Rainfall 4 months prior to harvest	Measured sucrose values	Calculated sucrose values[1]	Deviation
	Inches	*Percent-cane*	*Percent-cane*	
Jan. 1936	12.67	11.02	10.95	−0.07
Apr. 1936	1.36	13.09	12.98	− .11
June 1936	6.90	11.82	11.98	.16
Feb. 1937	11.86	11.45	11.09	− .36
Apr. 1937	5.57	12.63	12.22	− .41
Apr. 1937	5.57	12.78	12.22	− .56
May 1939	6.69	12.42	12.02	− .40
Jan. 1938	14.24	10.31	10.66	.35
Jan. 1938	14.24	10.48	10.66	.18
Feb. 1938	9.75	11.44	11.47	.03
Feb. 1938	9.75	11.20	11.47	.27
Mar. 1938	6.86	12.27	11.99	− .28
Mar. 1938	6.86	12.04	11.99	− .05
Apr. 1938	.92	13.29	13.06	− .23
May 1938	1.02	12.71	13.04	.33
Dec. 1939	20.38	9.37	9.56	.19
Jan. 1940	16.59	9.87	10.24	.37
Feb. 1940	14.19	10.66	10.67	.01
Mar. 1940	10.54	11.46	11.33	− .13
Mar. 1940	10.54	11.51	11.33	− .18
Apr. 1940	6.97	12.02	11.97	− .05
May 1940	7.58	12.20	11.86	− .34
Jan. 1941	21.10	9.53	9.43	− .10
Feb. 1941	15.97	10.69	10.35	− .34
Mar. 1941	6.82	11.61	12.00	.39
Mar. 1942	6.59	12.10	12.04	− .06
Apr. 1942	5.17	11.90	12.30	.40

[1] Calculated from the equation: $Y = 13.22 - 0.1797\ X_4$, where Y is the estimated sucrose percentage and X_4 is the total rainfall 4 months immediately prior to harvest.

McDonald (18), in Louisiana, all agreed that low night temperatures, especially in the months just previous to harvesting, improved the sucrose yields of cane.

Das (10) in his studies of the relation of weather to juice quality, in Hawaii, showed that the range of temperatures significantly affected the juice quality. A high temperature range, such as occurs when the days are bright and clear while the nights are cool, can be conducive to higher sucrose accumulation. Low ranges such as are usual when days are cloudy, exert an opposite effect.

The physiological processes involved in the ripening of cane are not yet clearly understood. However, Das' (8) explanation of the effects of day and

TABLE 7.—*Annual fluctuations in temperature (°F.) in 5 broad sugarcane-producing districts of Puerto Rico*[1]

Crop year	North	South	East	West	Interior	Mean
			Mean temperature			
1946	77.2	79.9	76.8	76.8	73.1	76.76
1947	77.8	80.6	78.0	77.7	74.8	77.78
1948	77.8	80.8	78.4	77.6	74.3	77.78
1949	77.1	79.2	77.1	76.6	73.8	76.76
1950	76.6	78.8	77.2	76.6	72.7	76.38
1951	77.3	79.8	77.5	77.4	75.2	77.44
1952	76.6	79.3	78.4	77.9	—	78.05
Mean	77.20	79.77	77.63	77.23	73.98	77.2
			Maximum temperature			
1946	89.9	92.7	87.8	91.1	86.6	89.62
1947	90.0	92.4	88.8	91.6	88.2	90.20
1948	90.2	92.9	88.9	90.7	88.6	90.26
1949	89.4	91.9	87.3	89.9	80.3	87.76
1950	88.1	92.0	86.9	89.6	86.3	88.58
1951	89.2	92.2	87.8	89.4	87.0	89.12
Mean	89.47	92.35	87.92	90.38	86.17	89.3
			Minimum temperature			
1946	65.8	66.4	64.9	62.2	61.4	64.14
1947	66.6	67.9	66.0	63.3	61.1	64.98
1948	66.0	67.5	66.5	64.2	59.6	64.76
1949	65.0	66.2	66.0	63.3	58.6	63.82
1950	64.4	65.4	65.6	63.0	58.2	63.32
1951	64.8	64.4	64.9	63.1	58.7	63.18
Mean	65.43	66.30	65.65	63.18	59.60	64.0

[1] The basic information for individual stations obtained from reports of the U. S. Weather Bureau was regrouped and averages were calculated for the sugarcane producing districts.

night temperatures seems logical:

Temperature during the daytime controls the processes of assimilation, translocation, and respiration of the plant. During the nighttime, the process of assimilation by which the leaf elaborates carbohydrates stops, but the other two processes still go on. The process of respiration causes a loss of material elaborated during the daytime; for some of the material is broken down to supply the energy for the chemi-

TABLE 8.—*Mean monthly variations in temperature (°F.) in 5 broad sugarcane-producing districts of Puerto Rico*[1]

Regions	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mean temperature												
North	73.9	73.4	74.3	75.9	78.0	79.6	79.6	80.2	79.9	79.4	77.6	75.3
South	77.1	76.9	77.3	79.0	79.9	81.6	82.0	82.5	82.4	81.4	80.3	78.4
East	73.9	73.8	75.1	76.1	79.2	80.4	80.4	80.6	79.6	79.4	77.5	75.2
West	73.8	73.8	74.8	76.4	78.3	79.4	79.6	79.6	79.5	78.9	77.6	75.0
Interior	70.7	70.7	72.1	73.6	75.5	76.9	76.1	77.5	77.2	76.4	73.5	72.7
Mean	73.88	73.72	74.72	76.20	78.18	79.58	79.54	80.08	79.72	79.10	77.30	75.32
Maximum temperature												
North	84.7	85.6	88.0	90.4	91.6	91.4	90.2	91.4	92.1	91.8	89.2	87.0
South	89.7	89.7	90.6	90.9	92.3	93.2	94.5	95.2	94.1	94.2	93.0	91.9
East	84.2	84.5	86.2	86.9	89.2	88.7	89.3	90.7	90.6	90.5	87.8	85.6
West	86.6	87.7	88.3	90.5	91.7	92.1	92.3	92.2	91.8	92.0	91.1	88.1
Interior	84.4	84.3	86.3	86.5	87.5	88.6	88.5	89.9	90.1	89.4	88.7	86.1
Mean	85.92	86.36	87.88	89.04	90.46	90.80	90.96	91.88	91.74	91.58	89.96	87.74
Minimum temperature												
North	61.9	60.8	62.2	63.1	66.8	67.4	68.6	69.3	68.3	68.0	65.9	63.0
South	62.6	61.2	63.0	65.3	67.7	69.6	70.0	69.6	69.2	68.4	67.1	63.9
East	61.8	60.2	59.9	63.7	67.8	69.6	70.0	69.8	68.6	68.6	66.0	62.4
West	59.9	58.9	58.9	61.0	64.2	65.7	66.1	66.1	66.7	65.9	64.1	61.2
Interior	55.9	58.4	55.9	57.7	60.8	61.9	61.0	62.4	62.4	62.3	67.3	58.8
Mean	60.42	59.90	59.98	62.16	65.46	66.84	67.14	67.44	67.04	66.64	66.08	61.86

[1] The basic information for individual stations obtained from reports of the U. S. Weather Bureau was regrouped and averages were calculated for the sugarcane producing districts.

cal reactions in the plant. Within certain limits, the higher the temperature, the greater the respiratory activity of the plant. Now, if we consider the total matter stored in the plant to be the difference between total matter assimilated and total matter lost by respiration then, we can see that relatively-high night temperatures will produce a greater loss of elaborated material and thus prevent the accumulation of a large amount of sucrose in the plant.

One of the striking features of the climate of Puerto Rico is the relatively uniform high temperatures that predominate throughout the year. On the

coast, variations are at a minimum; in the interior they are a little more pronounced. Table 7 shows the mean and the range of temperature for five broad geographical regions during the period 1946–52. Table 8 gives monthly fluctuations in temperature for the same regions. The following tabulation facilitates comparison of the yield data shown in table 3 and the temperature data in tables 7 and 8:

Region	*Mean sucrose yields, percent-cane*	*Mean differences between highest and lowest temperatures, °F*
South	12.14	26
West	11.94	27
Interior	11.46	27
North	11.23	24
East	11.06	22

In general, where the range in temperatures is wider, as in the south, the west, and the interior, and where the differences between maximum and minimum temperatures are from 26° to 28°F., sucrose yields are higher than in the north and east where the differences are only from 22° to 24°F.

In all probability in Puerto Rico, as in other areas where the temperature does not vary widely from year to year, the sucrose content of the cane is not so much influenced by the temperature as it is by rainfall. Statistical studies under way have shown some degree of correlation between the sucrose content of the cane at harvesttime and mean temperature throughout the growing and harvesting seasons in the west and interior districts of Puerto Rico. A summarized analysis of the significant data is given in table 9.

The regression coefficients are all negative, indicating that sucrose yields are depressed as the temperature rises. Although the regression was highly significant in the cases presented, there was no significance whatsoever in the majority of them. The temperature data used were not obtained by direct measurements in the months corresponding to the harvesting and grow-

TABLE 9.—*Summarized analysis of the significant data obtained in the west and the interior on the relationship between temperature and the sucrose content of sugarcane*[1]

Item	West			Interior	
Months before harvest the temperature of which was correlated with sucrose yields	5	6	12	1	4
Regression coefficient	−.45	−.94	−.74	−.13	−.28
Coefficient of determination	.89	.73	.77	.70	.87
Correlation coefficient	.94	.85	.88	.83	.93
F value	32.24**	18.38**	13.65**	2.86*	26.86*

[1] ** = Regression is highly significant; * = regression is significant.

TABLE 10.—*Relationships between sucrose yields, sunlight, and night temperatures in 5 broad sugarcane-producing districts of Puerto Rico*

Region	Mean sucrose yields 1947–52	Sunlight		Mean night temperatures
		Total	Mean per day	
	Percent-cane	*Day-degrees*	*Day-degrees*	*°F*
South	12.14	8,158	2.352	66.3
West	11.94	7,439	20.38	63.2
Interior	11.46	5,902	16.17	59.6
North	11.23	7,106	19.47	65.4
East	11.06	6,541	17.92	65.6

ing season, but by assuming that all the cane was harvested in April. This method, used also for rainfall, obviously introduced serious errors.

AS RELATED TO SUNLIGHT

Studies in Hawaii (7) indicated a close relationship between juice purities and the total number of clear days for the period 1902–16. Borden (2) compared the effect of full and decreased sunlight upon sucrose yields. Decreased sunlight was obtained by lining the tops and sides of glass-roofed sheds with burlap. Plants of variety 31-1389 were grown under identical conditions for 5 months when the treatment differentials were imposed. They were subsequently harvested at 12 months of age. Plants enjoying full sunlight yielded stalks containing 13.55 percent of sucrose and juices with 88.7-percent purity, while those grown under decreased sunlight produced only 9.27 percent of sucrose and juices of 80.2-percent purity. The differences were highly significant.

No direct solar-radiation measurements are yet available in Puerto Rico. Some have been taken at a north coast station and at a southern station. However, an indirect measurement may be useful. "Total day-degrees" has been correlated with sugar yields (2). This can be defined as degrees above 70°F. for a given period. If for a given day the maximum temperature is 85°F., the crop that day enjoys 15° in excess of 70°F. These measurements may be misleading on cloudy days when a very short period of sunshine may raise the temperature considerably.

As shown in table 10 both "total day-degrees" and sucrose yields increased or decreased together for the combined period 1947–52, except in the interior of the Island, where the night temperatures which drop below 60°F. seem to be dominant.

AS RELATED TO OTHER CLIMATIC FACTORS

In India, Somers-Taylor (21), correlated the sucrose content of sugarcane with the relative humidity of the atmosphere in the months prior to

TABLE 11.—*Mean monthly evaporation and wind velocity at 2 stations in Puerto Rico, as related to sucrose yielded by sugarcane, 1946-52*[1]

Station	Sucrose yields	Weather factor	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Percent-cane													
North (San Juan)	11.23	Evaporation (inches)	6.93	6.67	8.16	7.87	8.01	7.72	8.43	8.00	6.81	6.02	5.22	5.88
		Wind (mi./mo.)	5,675	4,553	6,302	4,900	3,827	4,644	4,043	4,139	3,191	2,713	4,414	5,165
West (Mayagüez)	11.94	Evaporation (inches)	3.45	3.86	5.30	4.98	4.52	4.21	4.14	4.28	4.12	3.98	3.68	3.17
		Wind (mi./mo.)	396	465	3,312	2,749	408	314	195	—	519	424	—	385

[1] The basic information on evaporation and wind velocity was obtained for individual years from the U. S. Weather Bureau and subsequently summarized for this report.

harvest. From his work it is evident that early ripening is induced by low humidities, while relatively high humidities tend to delay ripening.

The effect of length of day is involved with that of temperature and sunlight. The longer the days the more rapid the growth of the cane. Short days during harvesttime favor higher sucrose accumulations in the green-leaf section of the cane because of the favorable effects of lower night temperatures, which retard the process of respiration and thus favor the accumulation of sucrose in the plant cells.

Very little attention has been given to the effect, if any, of evaporation, wind, or any other climatic influences on the final sucrose concentration of cane at harvest. Verret and McLennon (26) measured the effect of wind currents on cane growth and observed a decrease in the total green matter produced by cane plants subjected to strong currents. However, this test, lasted only 56 days. A shredding of the cane tops of two varieties at three periods of growth was used to simulate the effect heavy winds might cause under field conditions (4). Variety 31-1389 was not affected, but in D. 1135 there was a pronounced effect on the purity and sucrose content of the juices when the shredded leaves were those attached to the twenty-third and the thirtieth nodes. This late shredding affected both the part of the stalk to which the shredded leaves were attached and the section immediately below. Earlier shreddings did not affect the sucrose yield of the canes.

Table 11 gives data on evaporation and wind velocity for two stations in Puerto Rico: San Juan in the north and Mayagüez in the west, for a limited number of years. Losses of water by evaporation are almost twice as much in the north as in the west. Winds blow with more intensity in the north, too. The strongest winds blow in San Juan from December to April, covering most of the sugarcane-harvesting season. In Mayagüez, winds are strongest during March and April. Sucrose yields over a period of years have been higher in the west than in the north.

INTEGRATED INFLUENCE OF WEATHER AND CLIMATE ON SUCROSE CONTENT OF SUGARCANE

Although attempts have been made to evaluate separately the probable influence on the sucrose content of cane of each climatic component, it must be realized that it is the integral effect, rather than the effect of each component separately, which really counts.

The results obtained from the experiments of Clements (6), in Hawaii, exemplify best the integral effect of climate upon the physiological processes active in sucrose formation and accumulation. Towards the middle of 1930, sugarcane variety 31-1389 was planted in large concrete pots filled with clayey soils taken from fields at Kailua and Waipio. Some replications were grown at Kailua and others at Waipio. At the former location days are

TABLE 12.—*Analysis of variance of the aggregate of the combined sucrose yields of several sugarcane crops harvested under 2 different climatic conditions*[1]

Source	Degrees of freedom	Sum of squares	Variance	*F* value
Total	47	22.55		
Climate	1	13.70	13.70	72.11**
Completely randomized error	46	8.85	.19	

[1] ** = Highly significant.

generally cooler and a fairly heavy rainfall is characteristic. At the latter days are bright and warm, but rainfall is scant. The Kailua crop received 154 inches of rain while the Waipio crop was irrigated with about 100 inches for the 22-month cycle. Despite similarity in fertilization and moisture conditions the Kailua crop was smaller in tonnage than that of Waipio, but the quality of the juices at Waipio were considerably better.

The classical work of Borden (3) with three varieties of cane, each grown on two different soil types under identical cultural conditions and all replicated under two distinctly different climatic conditions, emphasized the dominant effect of climate.

Data provided by Bonnet and coworkers[4] from their fertilizer experiments point to the influence of climate upon sucrose yields. Eleven crops of cane were grown at two locations: Río Piedras in the north and Guánica in the south. The former is characterized by a humid climate and sugarcane can generally be grown without supplemental irrigation, while at the latter the climate is semiarid and irrigation is necessary to grow a crop of cane successfully. Despite the similarities in fertilization the Guánica crops all contained more sucrose than the Río Piedras crops.

Table 12 summarizes the analysis of variance of the aggregate of all the combined crops from each location. The differences between locations are highly significant. The mean sucrose yields of all the combined Guánica crops was 12.96 percent-cane, while that of the Río Piedras crops was only 11.52, a difference of 1.44. A critical examination of the data from each individual crop reveals that the sucrose yields were invariably higher at Guánica than at Río Piedras. In spite of the recognized soil differences these large and consistent yield differences must be attributable to climate. The measured differences in sucrose content agree with data previously presented in figure 1.

SUMMARY

In the endeavor to ascertain the influence of some specific weather and climatic factors on the sucrose content of sugarcane at harvesttime in Puerto

[4] Bonnet, J. A., et al, Unpublished data.

Rico, data on past crops of such commercial varieties as, P.R. 902, M. 28, P.R. 905, P.O.J. 2878, and others, were re-examined and re-evaluated.

There were significant variations in the sucrose content of the same varieties when grown in the same regions in different crop years. These variations were related to weather conditions. Canes harvested at southern irrigated plantations with low rainfall consistently yielded more sucrose than those grown elsewhere, while those grown in the west were higher in sucrose than those grown in the interior, north, or east. In the former region field-irrigation schedules provide for a drying out of the cane from 45 to 60 days before harvest, while the cane was normally harvested during the drier season of the year in the other regions mentioned.

Generally speaking, high sucrose yields were also obtained in years of low rainfall, and vice versa. Sucrose yields were usually lowered if rainfall increased during the 3 or 4 months just prior to harvest. These effects were modified by soil conditions to some extent.

Sucrose yields were also generally higher in the south, west, and interior of the Island, where the temperature range varied from 26° to 28°F. between maximum and minimum, then in the north and east where such differences were in the neighborhood of 22° to 24°F. However, the influence of temperature was less than that of rainfall. Cool nights undeniably favored increased sucrose yields.

There was a direct relation between sunlight (as measured by "total day-degrees") and sucrose yields for the period 1947–52. Both factors increased or decreased together, except in the interior regions of the Island, where the night temperature which dropped below 60°F. seemed to be dominant.

The sucrose content of the cane could be correlated with atmospheric relative humidity, early ripening accompanying low humidity. Wind and evaporation also affected cane-sucrose yields, these being lower where the winds were strongest and the evaporation was presumably most rapid.

The integrated effect of these climatic and meteorological components is, however, the thing of primary importance. In spite of recognized soil differences, differences in yields of cane and sucrose are greatly affected by climate. The integrated effects of various climatic factors upon yields of sugarcane and of sucrose therein are presented in one table included in this report.

RESUMEN

En un esfuerzo por investigar el efecto específico que pudiera tener algún factor climático sobre el contenido de sacarosa en la caña de azúcar, al tiempo de cosecharse, se examinó y evaluó la información referente a algunas variedades comerciales de Puerto Rico, tales como las P. R. 902, M. 28, P. R. 905, P. O. J. 2878 y otras.

Se registran en este trabajo las variaciones significativas en el contenido

de sacarosa de una variedad que se ha venido cosechando en la misma región en años distintos. Estas variaciones estuvieron relacionadas con las condiciones del tiempo. Las cañas producidas en los plantíos bajo riego de la zona sur, donde la lluvia es muy escasa, produjeron siempre jugos de mayor contenido de sacarosa que las de todas las otras zonas, mientras que las cañas del oeste resultaron con mayor contenido de sacarosa que las producidas en las zonas del interior, norte y este. Es práctica rutinaria en la zona sur suspender los regadíos 45 ó 60 días antes de la cosecha. En las otras zonas donde no se riega la caña, se cosecha durante la época más seca del año.

En términos generales, se obtuvieron cañas con jugos más ricos en sacarosa durante los años en que la lluvia fué baja y vice versa. Generalmente los rendimientos de sacarosa fueron más bajos cuando la lluvia aumentó durante los 3 ó 4 meses anteriores a la cosecha. Dentro de ciertos límites estos efectos del clima se modifican de acuerdo con los del suelo.

Los rendimientos de sacarosa fueron generalmente mejores también en las zonas del sur, oeste e interior de la isla, donde las diferencias promedios entre las temperaturas máximas y mínimas fluctuaron entre 26° y 28°F., comparados con las zonas del norte y este, donde estas diferencias fluctuaron entre 22° y 24°F.. La influencia de la temperatura fué menor que la de la lluvia, sin embargo, no hay duda de que las noches frescas favorecen un aumento en los rendimientos de sacarosa.

Se encontró una relación directa entre la cantidad de luz solar, (medida en días-grados totales) y los rendimientos de sacarosa durante el período 1947–52. Ambos factores aumentaron o disminuyeron conjuntamente, excepto en el interior donde la temperatura durante la noche bajó hasta 60°F., lo cual parece ejercer una influencia dominante.

Los rendimientos de sacarosa de la caña se pueden relacionar con la humedad relativa de la atmósfera. Generalmente, una madurez temprana va asociada a una humedad relativa baja.

El viento y la evaporación también afectan los rendimientos de sacarosa, los cuales son más bajos cuando los vientos son más fuertes y la evaporación es más rápida.

El efecto integral de todos los componentes climáticos es de una importancia primordial. A pesar de las diferencias en los suelos, las variaciones en rendimientos de la caña y su sacarosa son grandemente afectados por el clima. Se presenta en forma tabular, la información que señala la importancia del efecto integral del clima sobre los rendimientos de sacarosa.

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The Influence of Potassium on the Yield and Sucrose Content of Sugarcane

George Samuels and Pablo Landrau, Jr.[1]

INTRODUCTION

Sugarcane is mainly grown for the production of sugar. The quantity of sugar produced per acre depends not only on the tonnage of cane produced, but also on the sucrose content of the cane. Increasing the sucrose content of the sugarcane by even a small fraction of a percent will appreciably increase the profit obtained by the cane grower.

Say a field produces 50 tons of millable cane per acre, with a mean sucrose-percent-cane concentration of 12 percent. This gives 120 hundredweights of sugar per acre. If by use of fertilizer we were to increase the sucrose content of the cane but 1 percent, from 12 to 13, the yield of sugar would be 130 hundredweights per acre. To get the same quantity of sugar per acre from 12-percent cane, it would be necessary to obtain yields of 54.2 tons. Thus, by harvesting 50 tons of 13-percent cane one grower obtains the same quantity of sugar per acre as another who harvests 54.2 tons of a 12-percent cane, with the added advantage that the latter does not have to pay the labor costs involved in harvesting an extra 4.2 tons of cane. He also receives added benefits from the sugarcane mill, because his cane is higher in sucrose, and likewise a larger share of the sugar profits.

The desire for a "sweeter" cane has given rise to many conflicting and inaccurate statements concerning the use of fertilizers and more particularly about their influence on cane sucrose content. Potassium has received the most attention as the fertilizer element that can raise the sucrose content of the cane. It has become common for cane growers to contend that the use of potash fertilizers produces "sweeter" cane. Many of them use high rates of potash application, even where no increase in cane tonnage could be expected, merely in attempts to increase the sucrose content of the cane.

The results obtained in practice and found in the literature have not clearly defined the role of potassium in influencing cane tonnage and the sucrose content of the cane. It is the purpose of this paper to present and interpret the data on the influence of potassium fertilization on cane yields and sucrose for Puerto Rico, as determined by over 40 years of fertilizer

[1] Plant Physiologist and Assistant Agronomist, respectively, of the Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P. R. This paper was presented at the 1953 meeting of the American Society of Agronomy at Dallas, Tex., on Nov. 17, 1953.

research conducted by the Agricultural Experiment Station of the University of Puerto Rico.

POTASSIUM AND CANE YIELDS

Potassium ranks second in importance as a fertilizer element in Puerto Rico, with nitrogen ranking first. When nitrogen was omitted from the cane fertilizer there was an average reduction of 30 percent in cane tonnage for all soil experiments carried on at this Station; when potassium was omitted the yield reduction averaged only 7 percent; the reduction due to omission of phosphorus was 4 percent.

In table 1 a summary is given of the yield increases attributable to potash applications on all soils of Puerto Rico where field experiments were established. The percentage increase in yield was greatest for the semiarid area. The humid area showed the next greatest increase; the yield increase averaged over 30 percent on the red and yellow and gray-brown podzolic soils of this area. The lowest responses were obtained in the irrigated area where, in some cases, applications of potash actually decreased yields.

The responses in cane tonnage to potash were usually higher than indicated in table 1, because the data include both plant canes and ratoon crops. The response to potash increased with increasing ratoons. An example of this is given in the following tabulation:

Crop	*Percentage increase in yield attributable to potash applications*
Plant cane	3.2
First ratoon	5.9
Second ratoon	5.9
Third ratoon	7.1
Fourth ratoon	12.8

The data are based on the means of four cane varieties. On this Coloso silty clay the percentage increase from potash application rose from 3.2 for the plant cane to 12.8 for the fourth ratoon, the rate of increase accelerating with each ratoon.

The amount of potash used in fertilizing sugarcane in Puerto Rico varies. Samuels and Capó (6)[2] found in a survy that an average of 129 pounds of K_2O per acre was used in the humid area and 73 pounds in the irrigated area. The potash is used almost exclusively as a component of the commercial mixed fertilizer applied to the cane. There are farms in the irrigated area to which no potash has been applied in the past 15 to 25 years, yet the cane shows no significant yield response to potash applications. Bonnet (2), in a 12-year fertilizer experiment, obtained no significant yield response to

[2] Numbers in parentheses refer to Literature Cited, p. 178.

the use of over 90 pounds of K_2O per acre on a Vayas clay in the irrigated area. In a similar experiment on the humid area, on a Vega Alta clay loam, significant responses were observed in the past few years to rates greater than 90 pounds K_2O per acre.

TABLE 1.—*Percentage changes in sugarcane yield attributable to applications of potash in experiments conducted in different areas and on different soils of Puerto Rico, by the Agricultural Experiment Station, University of Puerto Rico*

Soil series	Soil group[1]	Number of experiments[2]	Mean percentage increase or decrease in yield attributable to potash applications
	Humid area		
Coloso silt loam	Alluvial	10	11.6
Coloso silty clay	do.	47	12.0
Estación silt loam	do.	2	3.3
Fajardo clay loam	Red and Yellow Podzolic	5	33.2
Moca loam	do.	1	36.4
Toa silty clay loam	Alluvial	2	3.3
Vega Baja silty clay	do.	16	17.8
Vía silty clay	Gray-Brown Podzolic	2	34.0
Weighted mean		85	14.7
	Semi-irrigated area		
Coto clay	Yellow-Brown Lateritic	14	6.1
	Irrigated area		
Aguirre clay	Alluvial	2	6.9
Altura silt loam	do.	2	−1.2
Coamo clay	Chernozem	2	1.8
Fraternidad	Reddish Chesnut	12	−4.8
Machete clay	Reddish Prairie	2	−6.1
Mercedita clay	Reddish Chesnut	2	5.2
Weighted mean		22	−2.0
	Semiarid area		
Santa Isabel silty clay loam	Planosol	8	24.0
Weighted mean for all soils		129	11.9

[1] As classified by Roberts (5). See test footnote 2.

[2] Each variety and crop counted as a separate experiment.

POTASH AND SUCROSE-PERCENT-CANE

The influence of potassium on the sucrose content of sugarcane is related to the yield response of the cane. Samuels, et al. (7) found that a direct linear relationship existed for sugarcane in Puerto Rico between the percentage increase in yield and the percentage increase in sucrose concentration, as both factors were influenced by potash applications. The percentage increase in cane tonnage per acre when potash was applied was plotted against the corresponding increase in sucrose-percent-cane. These data were brought up to date for over 200 experiments and the results are shown graphically in figure 1. They indicate that an increase in sucrose content accompanies increases in cane tonnage. The relationship obtained was highly significant. The equation expressing this relationship was $Y = 0.12$

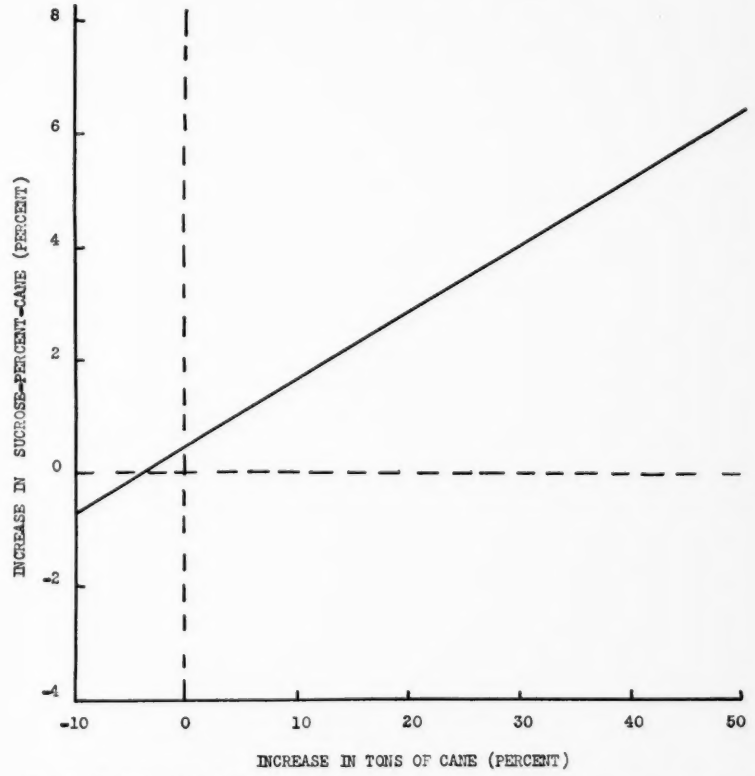

FIG 1.—Relationship between the percentage increase in tons of cane per acre and in sucrose-percent-cane when potash was applied to the sugarcane.

$x + 0.55$, where Y is the percentage increase in sucrose-percent-cane content and x is the percentage increase in tons of cane per acre when potash was applied.

In those cases where yield increases from potash applications were 10 percent or less, the sucrose concentrations were not consistently influenced, and they fluctuated between positive and negative responses. However, when yield increased more than 10 percent, the sucrose content of the cane increased accordingly in response to potash applications. It appears, therefore, that the application of potash fertilizers to sugarcane will not appreciably increase the sucrose content of the cane if it does not increase cane tonnage at the same time. "Luxury" use of potash fertilizers does not make "sweeter" cane unless potash is deficient in the soil for normal cane yields.

Although the cane growers are mainly interested in producing more sugar per acre, the sugarcane factory is also concerned with having more sugar produced per ton of cane. It, therefore, must consider the various components of the term sucrose-percent-cane. The calculation of available 96° sugar-percent-cane depends on the Brix of the juice, its polarization, and the percentage of juice extracted from the cane by the mill.

Using data from field experiments where potash significantly increased cane tonnage and sucrose concentration, a study was made of the influence of potassium on such individual components of the available 96° sucrose-percent-cane as polarization, Brix, and percentage of juice extracted. There was a general significant increase in polarization with increased potash applications. Brix and percentage juice extraction showed no significant trends. An example of the influence of potash fertilizers on the components of sucrose-percent-cane is given in figure 2.

Potassium applications mainly influenced the available 96° sugar-percent-cane content by increasing the polarization value. There was no apparent influence on the total solids in solution (Brix) or on the percentage extraction of the juice that could be attributed to the potash applications.

METHODS OF DETERMINING THE POTASSIUM NEEDS OF SUGARCANE IN THE FIELD

Potash applications produced increases in sucrose concentration in the cane when corresponding increases in tonnage were obtained. Thus, cane deficient in potassium will suffer in both tonnage and sucrose content. However, showing that a potassium deficiency reduces cane yields and sucrose content is not enough. The next step is to find methods of detecting these deficiencies in the field so that potash may be applied to cane needing this fertilizer, and will not be wasted on cane that has no need for it. As was shown previously not all sugarcane in Puerto Rico needs large applications

of potash. In fact, certain soils have shown no response to potash, even though cropped to sugarcane for many years without applications of potash.

Several methods have been tried of determining the potash fertilizer requirements for sugarcane in Puerto Rico. Capó (3), utilizing a modification of Mitscherlich's pot-test method with sorghum as the indicator crop, obtained values of K_2O available for crop use ranging from 125 to 2,961 pounds per acre. Field experiments failed to substantiate this finding by pot tests. Jeffries (4), in a mineralogical study of some of the soils of Puerto Rico, found substantial quantities of a beidellitic type of clay mineral, montmorillenite, and illite, as well as the expected kaolinite clay mineral; however, no immediate difference was apparent in the potassium-fertility status of any soil in which the clay minerals were identified. Bonnet (1) reported on available potash extracted by a 1-percent citric acid solution from the surface soils of Puerto Rico. He found no significant difference between the mean value for the soils of the humid area and for those of the irrigated and semiarid areas.

At present potash deficiency in cane is being detected in the field in Puerto Rico by the use of foliar diagnosis. Decisions as to whether or not potash fertilizers are needed are now being made in some areas of the Island in

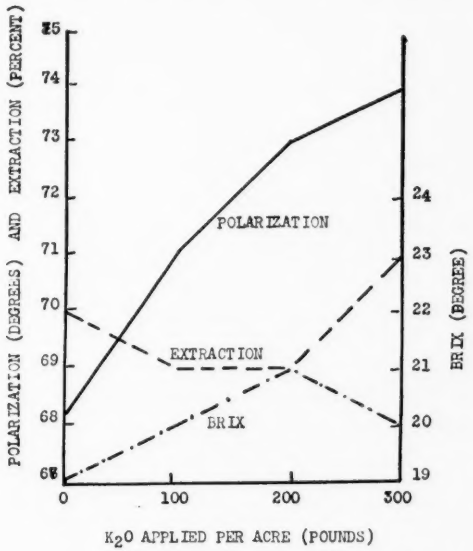

FIG. 2.—Influence of potassium fertilizer applications on Brix, polarization, and percentage juice extraction of sugarcane.

regular commercial practice, using cane-leaf samples taken at a cane age of 3 months. Potash levels in the leaf indicating deficiency or adequacy have been worked out from detailed experiments conducted by the Agronomy and Horticulture Department of the Agricultural Experiment Station. The experiments were conducted on the leading soil series with the most popularly used cane varieties under treatments with several levels of nitrogen, phosphorus, and potassium. In all treatments where the potash was varied, nitrogen and phosphorus were added at optimum levels. The leaf samples were taken from replicated plots and yields data were collected when the experiment was harvested. The leaf values were compared with cane yields to determine whether the levels found were associated with significant yield responses.

Leaf-potassium values of 2 percent or more, on a dry-weight basis, were found to be associated with no response to potash fertilizers for all soil areas. Values of 1.75 percent or more generally proved to be an adequate level for which no responses to potash applications could be expected. On

TABLE 2.—*Leaf-potassium values for sugarcane from selected experiments and their relation to cane yields and potash applications*

Potash application	Leaf potassium on dry-weight basis	Yield of cane in 96° available sugar per acre
	Normal response (Coloso silty clay—plant cane)[1]	
Pounds	*Percent*	*Cwt.*
0	1.54	89
150	1.92	105[2]
300	2.42	110
	Severe deficiency (Vía silty clay—plant cane)[3]	
0	0.44	91
100	.96	109[2]
200	1.09	112
300	1.17	120
	No response (Machete clay—second ratoon)[4]	
0	3.60	86
120	3.53	80
240	3.17	84
360	3.54	81

[1] The mean of 4 varieties at Central Coloso experiment, Aguadilla.
[2] Response significant at 1-percent level over no potash treatment.
[3] One variety at Colonia Santa Teresa experiment, Humacao.
[4] One variety at Colonia Esperanza, Aguirre.

soils where experiments showed severe potash deficiency, such as the Vía silty clay and the Santa Isabel silty clay, the use of rates as high as 300 pounds of K_2O per acre failed to raise leaf-potassium levels over 1.80 percent. In table 2, examples are given of three types of conditions encountered in the use of foliar diagnosis for potash with sugarcane: Severe deficiency, normal response, and no response with "luxury" consumption.

Although visual evidence of potassium deficiency has been obtained on sugarcane in greenhouse work, it is not normally seen in the field and recognized as such. When deficiences of potassium are evident visually, the cane is usually suffering from very severe deficiencies. However, the foliar-diagnosis technique facilitiates the detection of potash deficiency in cane fields where visual symptoms were not apparent, and fertilizer can still be applied to correct the deficiency.

SUMMARY

Critical analysis of the results of over 200 field experiments with potash fertilizers on sugarcane conducted by the Agricultural Experiment Station of the University of Puerto Rico, covering a wide ranges of cane varieties and soils types of Puerto Rico, revealed the following:

(1) Potash increased cane yields mainly on the red and yellow podzolic soils of the humid area and on a planosol of the semiarid area. There was slight, if any, response to potash in the irrigated area.

(2) The use of potash increased the sucrose concentration of the cane only if cane yields were also increased. Increases of 10 percent or more in tonnage were required if increases in sucrose content were to be expected. A linear relation $Y = 0.12\,x + 0.55$ was obtained where Y was the percentage increase in sucrose-percent-cane and x the percentage increase in tons of cane yielded per acre.

(3) When potash fertilizers significantly influenced the sucrose concentration of the cane, the polarization value of the cane juice increased. Brix and percentage extractability of juice were not appreciably affected.

(4) The use of foliar diagnosis has proven to be of great value in Puerto Rico in determining when to apply potash fertilizers to sugarcane. Leaf values of 2 percent or more, on a dry-weight basis, indicate that no response to potash applications can be expected for soils and varieties in Puerto Rico. Values below 1.80 percent indicate that a response to potash fertilizers may be expected in the humid areas.

RESUMEN

Los análisis críticos de los resultados de más de 200 experimentos de campo, llevados a cabo por la Estación Experimental Agrícola de la Uni-

versidad de Puerto Rico, sobre el uso de los abonos potásicos para la caña de azúcar, los cuales cubrieron una gran diversidad de variedades de caña y de tipos de suelos, demostraron lo siguiente:

(1) La potasa aumentó los rendimientos de la caña, principalmente, en los suelos podzólicos rojos y amarillos de las áreas húmedas y en un suelo planosol, cuya área era semiárida. Apenas respondió la caña a las aplicaciones de potasa en las áreas bajo riego.

(2) El uso de la potasa aumentó la concentración de la sacarosa, siempre y cuando se aumentaran los rendimientos de la caña. Aumentos del 10 por ciento o más en tonelaje tenían que obtenerse para que se aumentara el contenido de sacarosa. Una relación lineal $Y = 0.12\,x + 0.55$ se obtuvo cuando Y representó el porcentaje de aumento en el por ciento de sacarosa en la caña y x el porcentaje de aumento en toneladas de caña obtenidos por acre. El Brix y el porcentaje de extracción del jugo no se afectaron apreciablemente.

(3) El valor de la polarización del jugo se aumentó cuando la aplicación de los abonos potásicos influyeron significativamente sobre la concentración de sacarosa en la caña.

(4) El uso del diagnóstico foliar ha demostrado ser de gran utilidad en Puerto Rico para determinar cuándo deben aplicarse abonos potásicos a la caña de azúcar. Los valores de un 2 por ciento o más en las hojas (base seca) indican que no se puede esperar que los suelos y las variedades en Puerto Rico respondan a las aplicaciones de potasa. Los valores más bajos de 1.80 por ciento indican que puede esperarse que los suelos y las variedades respondan a la potasa en las áreas húmedas.

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The Effect of Differential Sugarcane Fertilizer Treatments on a Coloso Silty Clay

George Samuels and Pablo Landrau, Jr.[1]

INTRODUCTION

There are many factors to be considered in relation to soil properties and fertility, such as climate, parent material, and vegetative cover. However, one of the important factors normally denied due consideration is man. For man can modify many of the properties of the soil by his management. By improper management he can accelerate erosion or lower soil fertility. Using proper agronomic practices, he can prevent erosion and increase crop yields.

In many agricultural areas one crop is grown continuously on the same soil using the same fertilizer practices year after year. This is true of many of the sugarcane lands of Puerto Rico. Over 150,000 tons of fertilizer are being applied yearly to the sugarcane grown in Puerto Rico. Typical applications are equivalent to 1,200 pounds of a 12-4-10 mixed commercial fertilizer per acre per year placed on the fields (7)[2]; meanwhile, 40 to 50 tons of cane per acre per year are removed from these fields. The sugarcane soil is not a static condition here, but rather in one of constant change involving large fertilizer additions and the removal of plant nutrients by the cane. Depending on the type and quantity of fertilizer he uses, man can readily modify the fertility of the soil.

OBJECTIVES

It is the purpose of this study to show in what manner the use of certain differential fertilizer treatments has influenced certain chemical properties of the soil to which the fertilizer was applied.

The study covers 9 years of differential fertilizer treatments on a Coloso silty clay, and their effects on soil pH, organic matter, and nitrogen, and on the "available" phosphorus and potassium supply. A detailed study of the cane yields and their response to the fertilizer treatments has been made by Samuels and Landrau (8). A balance sheet will be presented of the quantities of plant nutrients added to the soil by the fertilizer and

[1] Plant Physiologist and Assistant Agronomist, respectively, of the Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P. R. The authors wish to acknowledge and thank for their cooperation F. A. Abruña, Soil Scientist, S. Silva, Soil Scientist Aid, and J. Figarella, Soil Scientist, all of the cooperative ARS. Project of the Agricultural Experiment Station, for their help in taking the soil profile and making the physical and chemical analyses of the profile.

[2] Numbers in parentheses refer to Literature Cited, p. 187.

the cane trash, and of the materials removed by the harvested cane stalks, to demonstrate the dynamic flow of materials in the soil which influence soil properties.

PROCEDURES

The experimental field was located on a Coloso silty clay soil of field 9, San Francisco Farm, of the Cambalache Area of the Land Authority of Puerto Rico. The site of the experiment is 8 km. from the city of Arecibo on the Arecibo-to-Utuado road.

This was a sugarcane fertilizer-variety experiment begun on September 18, 1944, with a plant cane aged 17 months, and continued for five ratoons averaging 12 months each, and another plant cane of 18 months. Four sugarcane varieties (P.O.J. 2878, P.R. 903, M. 275, and M. 317) and seven different fertilizer levels of nitrogen, phosphorus, and potassium were utilized (see table 1). The design of the experiment was a split-plot one, in which varieties were considered as the whole-plot effect and the various fertilizer levels were regarded as the sub- or split-plot effect. The plot size was approximately $\frac{1}{172}$ of an acre, and the fertilizer treatments were replicated nine times for each variety.

In March 1953, following the harvesting of the second plant cane, soil samples were taken from each plot of the various fertilizer treatments for one variety (P.O.J. 2878), using a soil-sampling tube to a depth of 12 inches. The samples were removed from the side of the cane stool, in the furrow, three samples per row of cane (at the beginning, middle, and end of each row) and for the four rows in the plot. Thus a total of 12 samples per plot was taken. These samples were composited for each plot. The soil samples were air-dried, passed through a 2-mm. sieve to remove stones and organic debris, and then analyzed.

TABLE 1.—*Fertilizer applied per acre for the sugarcane experiment on a Coloso silty clay at Arecibo*

Treatment No.	Fertilizer applied per acre as—		
	N	P_2O_5	K_2O
	Pounds	*Pounds*	*Pounds*
1	0	300	300
2	125	300	300
3	250	0	300
4	250	150	300
5	250	300	0
6	250	300	150
7	250	300	300

Nitrogen was determined by the standard Kjeldahl method; pH was determined electrometrically by means of a Macbeth pH-meter; and organic matter by the Schollenberger colorimetric method. A 1 N ammonium-acetate extract of the soil was used for determining available phosphorus and potassium. The phosphorus was determined colorimetrically, and the potassium by means of a flame photometer.

The values obtained from the chemical analyses were all analyzed statistically to determine whether differences obtained between treatments were significant.

An undisturbed soil core was taken of the Coloso silty clay at the margin of the field in order to evaluate the general characteristics of this soil type as it appeared in this area. The sample was taken to a depth of 72 inches by using a Kelly soil-sampling machine (3). The soil core was differentiated into horizons, and certain morphological, physical, and chemical tests were made on these horizon samples. The methods and procedures used for permeability measurements, quick drainage, pF, and volume weight were given in detal in another publication(4).

THE SOIL

The Coloso silty clay of which there are 14,976 acres in Puerto Rico (6) is a poorly drained soil of the river flood plain which occurs in the humid and subhumid sections along the western, northern, and eastern coasts of Puerto Rico. The soil is normally only a few feet above sea level, the water table averages less than 24 inches from the surface, and most of the areas are subjected to frequent inundations and sedimentations. The soils are heavy-textured, having been formed from the slow accumulations of sediments derived from neutral fine-textured materials washed from soils derived from fine-grained volcanic rock and limestone. The subsoil is a heavy plastic clay, mottled and poorly drained.

On March 11, 1952, a profile of a Coloso silty clay was examined at the border of the sugarcane experiment at the San Francisco Farm near Arecibo. The land was flat with no apparent signs of erosion and some signs of deposition, and the vegetative cover was sugarcane. The root development was very good down to a depth of 20 inches. All horizons had a fine-sized internal porosity and a moisture content above field capacity.

0–14″ Plow layer of dark grayish-brown dense silty clay with grayish mottling spots near surface. Moderate blocky structure with some horizontal overlap. pH 6.0 for the 0–6″ layer and 6.8 for the 6–12″ layer.

14–26″ Dark-brown dense clay with dark grayish-brown mottling spots. Moderate to weak fine blocky structure with vertical overlap. pH 6.8.

TABLE 2.—*Permeability and other soil-moisture data on soil cores from a Coloso silty clay*

Depth (inches)	Permeability	Water drained at 60 cm. in 15 minutes	Maximum saturation	Water remaining at pF of—			Available water (water held between pF. 1.9 and pF 4.2)	Volume-weight
				1.9	2.7	4.2		
	In./hr.	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Cm./c.c.*
0–7	1.96	0.6	54.7	51.0	34.7	21.2	29.8	1.20
7–14	.78	1.7	50.9	44.7	36.3	23.0	21.7	1.30
14–26	7.00	2.3	52.1	47.7	34.8	25.3	22.4	1.27
26–33	1.98	1.0	51.3	48.3	35.5	27.5	20.8	1.29
33–40	2.80	1.3	51.3	48.5	35.9	28.1	20.4	1.29
40–56	1.58	1.0	52.1	49.9	39.2	29.7	20.2	1.27

26–40″ Dark grayish-brown heavy clay quite similar in color to surface horizon, and suggestive of deposition. Moderate blocky structure with horizontal overlap. pH 7.0.

40–56″ Gray and yellow mixed heavy dense clay with some iron concretions. Moderate to weak large blocky structure with both horizontal and vertical overlap. pH 6.9.

The physical properties of the profile are given in table 2. The percolation rate was slow throughout the profile except for the 14–26-inch layer which had high values caused by worm and root holes. The quick drainage (water drained at 60 cm. in 15 minutes) was low, indicating the poor drainage obtained in this soil. The maximum saturation values were high (above 50 percent) and changed very little throughout the profile. The water remaining at pF 1.9 averaged 48.4 percent and showed a high field capacity. The values were high at pF 4.2 (considered the permanent wilting point) indicating that the soil retained large amounts of water unavailable for the use of the plant.

If the available water for the crop is regarded as the difference between water remaining in the soil when tensions equivalent to pF 1.9 are applied and that remaining when permanent wilting occurs (pF 4.2), this soil does have a moderately high water-supplying power, despite its high values at the permanent wilting point. In general, the physical values show that this soil, Coloso silty clay, is one where drainage and excess water are problems to be contended with in growing crops.

EXPERIMENTAL RESULTS

Unfortunately, soil samples were not taken at the initiation of this experiment in 1944, so that comparisons could not be made with original soil values. However, the influence of nitrogen, phosphorus, or potassium fertilizers on the soil can readily be determined by comparing those treatments

TABLE 3.—*The influence of fertilizer levels for sugarcane on certain chemical soil properties of a Coloso silty clay*

Treatments (pounds per acre)			Organic matter	Soil pH	Soil N	Available soil P	Available soil K
N	P_2O_5	K_2O					
Nitrogen treatments							
			Percent		*Percent*	*P.p.m.*	*P.p.m.*
0	300	300	2.0	5.9	0.14	40	110
125	300	300	2.1	5.8	.14	37	86
250	300	300	2.1	5.7	.13	36	81
Phosphorus treatments							
250	0	300	2.2	5.6	0.14	32	83
250	150	300	2.0	5.7	.14	32	84
250	300	300	2.1	5.7	.13	36	81
Potassium treatments							
250	300	0	2.1	5.6	0.14	31	61
250	300	150	2.2	5.7	.14	36	79
250	300	300	2.1	5.7	.13	36	81
Least significant difference needed between treatments at:							
5-percent level			—	—	—	8	12
1-percent level			—	—	—	11	16

where a particular fertilizer element was varied from none to high applications. A summary of the values obtained for certain chemical soil properties at different fertilizer levels is given in table 3.

SOIL ORGANIC MATTER

The organic-matter content of the soil was not significantly influenced by variations in nitrogen, phosphorus, or potassium fertilizers. Although the no-nitrogen treatment averaged 26 tons of cane less per acre than the 250-pound-N-per-acre treatment (table 4, treatment 1 minus treatment 7), there was still sufficient organic material produced by roots, stubble, and cane trash of the 40 tons per acre to maintain the organic-matter content of the soil.

SOIL NITROGEN

The nitrogen content of the soil showed no significant variation with any of the fertilizer treatments used. The no-nitrogen treatments revealed no lower soil-nitrogen content, although no nitrogen fertilizer had been applied

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TABLE 4.—*Mean yields of 4 sugarcane varieties grown at different fertilizer levels for 7 crops*

Treatment No.	Treatments in pounds per acre of—			Cane per acre	Available 96° sugar per acre	Sucrose in cane
	N	P_2O_5	K_2O			
				Tons	*Cwt.*	*Percent*
1	0	300	300	40.0	91	11.84
2	125	300	300	58.5	133	12.09
3	250	0	300	65.0	144	11.90
4	250	150	300	65.7	145	11.87
5	250	300	0	61.3	133	11.57
6	250	300	150	65.2	141	11.69
7	250	300	300	65.2	147	11.94
Mean for all treatments				60.1	134	11.84

for 9 years. Nor did increasing increments of nitrogen (125 and 250 pounds of N per acre respectively) increase the soil nitrogen over the level of the no-nitrogen plots.

SOIL pH

The use of various fertilizer levels did not significantly influence soil pH. During the 9 years of the experiment a total of 8,750 pounds of sulfate of ammonia were applied to the 250-pound-N-per-acre plots. This represents an equivalent acidity that would require 9,630 pounds of calcium carbonate to neutralize. No lime was applied in this experiment but, as can be seen from table 3, the pH of the soil was not decreased significantly when ammonium sulfate treatments are compared with the no-nitrogen treatment.

When used over long periods ammonium sulfate has been found to lower the pH of the soil. Cooper (1) stated that the use of 250 pounds of ammonium sulfate yearly for 21 years on an Orangeburg fine sandy loam lowered the pH from 5.9 to 4.9 in South Carolina. Chardón and Méndez (5) found that the use of 625 pounds of ammonium sulfate annually for 6 years did not lower the pH of a Vega Baja silty clay with a pH of 5.9. The use of ammonium sulfate for 9 years failed to lower the pH of the Coloso silty clay.

However, there are certain compensating factors which tend to nullify the acidity of the sulfate of ammonia in this experiment. One is the heavy texture of the silty clay with its high buffer capacity as compared with the light texture of the sandy loams of the eastern United States. Another aid in counteracting the acidity of the ammonium sulfate is the large quantity of base returned by the cane trash. A 50-ton crop of cane will return bases to the soil equivalent to approximately 1,750 pounds of $CaCO_3$[3].

[3] Based on a 4:1 cane-to-trash ratio with a 1.8 percent CaO and 1.6 percent MgO content (2) of the cane trash on a dry-weight basis.

AVAILABLE SOIL PHOSPHORUS

There was no significant difference in available soil phosphorus for any of the treatments (table 3). Soil phosphorus showed no significantly lower value when no phosphorus was applied than when 300 pounds of P_2O_5 per acre were applied. There was no increase in cane tonnage or sugar that could be attributed to the use of the phosphate fertilizers (table 4). It appears, therefore, that values of over 30 p.p.m. available soil phosphorus are adequate for the Coloso silt loam to produce optimum yields.

AVAILABLE SOIL POTASSIUM

Significantly lower available soil-potassium values were obtained when no potash had been applied for 9 years as compared with the potash-treated plots (table 3). There were also significant differences in yield attributable to the use of potash (table 4). It appears from these results that, for this experiment, values of available soil potassium of 60 p.p.m. or less, indicated a definite deficiency of potassium. Soil-potassium values were not significantly changed when 300 pounds of K_2O were applied in lieu of 150 pounds per acre.

The available potassium increased significantly where no nitrogen was used (table 3). In fact, the available potassium increased with decreasing nitrogen applications. This may be attributed, in part, to the fact that yields were 20 tons lower when no nitrogen was applied to the soil, hence the crop removed less potassium from it.

DISCUSSION

Cropping of sugarcane for over 9 years at various fertilizer levels had no significant influence on the level of organic matter, nitrogen, pH, and available phosphorus in a Coloso silty clay soil.

It would perhaps seem logical that removing an average of 50 tons of cane per acre yearly from the soil would produce some measurable changes in soil fertility. The omission of nitrogen and potassium fertilizers did not significantly reduce cane tonnage or sugar content. From a soil-chemical standpoint we could detect only a reduction in "available" soil potassium. Soil organic matter and nitrogen were of no value as guides to the nitrogen-fertility status of this soil.

One possible reason for the lack of large changes in certain chemical soil indices is the cane crop itself. For even when 50 tons of cane per acre are taken away yearly, a high percentage of organic matter and mineral elements remains behind as cane trash (dried cane leaves, tops, and stubble). In table 5 a summary of the quantity of materials removed from the field and that left behind is given. On harvesting 50 tons of cane per acre there are removed from the field 43 pounds of N, 43 pounds of P_2O_5, and 59 pounds of K_2O per acre. Left behind in the trash to decompose and enter

TABLE 5.—*Quantities of plant nutrients and fertilizer materials involved in harvesting a 50-ton crop of P.O.J. 2878 growing on a Coloso silty clay at Arecibo*

Item	Nutrient content per acre as—			Fertilizer equivalent per acre as—		
	N	P_2O_5	K_2O	Ammonium sulfate (20-percent N)	Superphosphate (20-percent P_2O_5)	Potassium chloride (60-percent K_2O)
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Millable cane stalks[1]	43	43	59	215	215	100
Cane trash[2]	150	97	285	750	485	475
Total	193	140	344	965	700	575
Fertilizer added	250	300	300	1,250	1,500	500

[1] Based on a 73-percent cane-stalk moisture and a nutrient content of 0.16 N, 0.07 percent P, and 0.18 percent K, on a dry-weight basis.

[2] Based on a 4:1 cane stalk-to-dry-trash ratio with an average nutrient content of 0.6 percent N, 0.17 percent P, and 0.93 percent K, on a dry-weight basis.

the soil are approximately 150 pounds of N, 97 pounds of P_2O_5, and 285 pounds of K_2O per acre. The trash also contributes 2,000 pounds of humus (C:N ratio 10:1) to the soil in return for the 50 tons of cane harvested.

It is apparent from table 5 that large quantities of plant nutrients are in transit in the soil. There is the material added by man, in this case as inorganic fertilizers, the nutrients removed by the harvested cane, and those materials in organic form returned to by the trash. This large interchange of plant nutrients has buffered some of the expected changes in chemical soil properties which might be associated with constant cropping at different fertilizer levels. At least for the Coloso silty clay cropped for over 9 years to sugarcane at various fertilizer levels, the influence of these fertilizer levels on certain chemical soil properties was not as appreciable as was the fertilizer influence on cane yield.

SUMMARY

The findings in this study of the influence of different fertilizer levels on a Coloso silty clay for over 9 years of sugarcane cropping were:

(1) A morphological description of a Coloso silty clay profile is given together with data on certain physical properties of the soil.

(2) There were no significant differences in soil organic matter, nitrogen, or available phosphorus attributable to any of the fertilizer levels used.

(3) The available soil-potassium values were significantly lower where no potash was applied than where potash treatments were used.

(4) There were no differences in soil pH where sulfate of ammonia was used as compared with the no-nitrogen treatment.

(5) A discussion is presented of the amounts of plant nutrients removed from the soil by the cane and added to it in the cane trash. This indicates that when sugarcane is grown, large quantities of plant nutrients are in transit in the soil, and this interchange of plant nutrients buffers some anticipated changes in chemical soil properties that might otherwise be associated with constant cropping.

RESUMEN

La influencia de distintos niveles de abonamiento sobre un suelo Coloso limoarcilloso sometido durante 9 años al cultivo de la caña de azúcar, se reveló como sigue:

(1) No hubo diferencias significativas en cuanto a materia orgánica, nitrógeno o fósforo asimilable que pudieran atribuirse a alguno de los niveles de abonamiento usados.

(2) Los valores del potasio asimilable en el suelo fueron significativamente menores donde no se aplicó potasa que donde se aplicó.

(3) No hubo diferencias en el pH del suelo cuando se usó sulfato amónico en comparación con el tratamiento donde no se usó este elemento fertilizante.

En este trabajo se incluye una descripción morfológica del perfil Coloso limoarcilloso, como también datos sobre ciertas propiedades físicas del suelo. Se discute, a la vez, sobre la cantidad de nutrimentos que la caña remueve del suelo y que luego pasa, en parte, a la paja.

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Identification, Occurrence, and Distribution of Strains Sugarcane Mosaic in Puerto Rico

G. W. Bruehl[1]

INTRODUCTION

Many aspects of the mosaic disease were studied in Puerto Rico in the pioneering efforts following the mosaic epidemic of 1916–19 (13).[2] Control measures were successfully applied as knowledge and understanding of this disease increased. Research upon mosaic diminished when the press of necessity lessened. Mosaic has been present constantly in parts of Puerto Rico since its introduction, maintained in a small percentage of infected plants in B. H. 10(12), and in scattered stools of P.O.J. 36, D. 1135, and probably in other susceptible varieties occurring as unnoticed remnants among resistant canes in mixed plantings. Many grasses other than sugarcane are susceptible (15) and could serve as reservoirs of the virus, but observations indicate that mosaic does not survive long in grasses here. B. 34104 was recently propagated extensively on the lowlands of the south-central and south-eastern sections of the Island, in contact with B.H. 10(12), and from there has spread to smaller plantings in many localities. This variety was quickly infected (7), and the infection is spreading in M. 336 (4) and B. 37161. The resurgence of mosaic from a minor, controlled disease to a spreading major problem has stressed the need for further research.

REVIEW OF THE LITERATURE

In an extensive breeding program adequate testing for disease resistance is aided by a knowledge of the presence or absence of strains of the pathogen, and studies on the most practical methods of inoculation in various stages of selection. Summers (14) pioneered in the identification of strains of the mosaic virus in Louisiana, and eventually (15) several strains, differing in virulence, infectivity, and type of symptoms produced on certain differential varieties, were described. Abbott (3) reported differences in the

[1] Plant pathologist, Sugar Plant Investigations, Agricultural Research Service, United States Department of Agriculture, in cooperation with the Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P. R. The author wishes to express his gratitude for the counsel of Dr. E. V. Abbott, U.S.D.A. Sugar Plant Experiment Station, Houma, La., and for the cooperation of many individuals and agencies in the collection of mosaic-infected canes, and particularly Mr. P. González-Ríos, Head, Department of Plant Breeding, Agricultural Experiment Station, Río Piedras, P. R.

[2] Numbers in parentheses refer to Literature Cited, p. 197–8.

ability of some of these strains to withstand heat and dilution. Knowledge of strains of mosaic in Puerto Rico dates from the interception of strain B on B.H. 10(12) from Puerto Rico in the quarantine houses in Arlington Farm, Va. (11). Jensen (8) observed symptoms in commercial fields suggesting the presence of two or more strains.

Bruehl (5) identified strains apparently identical with those described by Summers. The completion of the strain survey of 1952–53 is presented in this paper. The potential severity of mosaic in continental United States with its several virulent strains of the mosaic virus has led to the general use of the inoculation of very young seedlings with juice and carborundum (1), and the immediate rejection of all plants showing symptoms subsequent thereto. This technique was used on 8,000 seedlings of the 1953 crosses and was considered successful. Both the Sein (12) and Matz (10) methods were tried on plants grown from cane pieces.

MATERIALS AND METHODS

Canes from infected plants were selected from fields in as many locations and planted to as many varieties as possible. These canes, comprising a sample of the mosaic virus in Puerto Rico, were brought to Río Piedras where they were propagated and grown until sufficient leaf material was formed to permit juice extraction and inoculation. The differential varieties (15) C.P. 31/294 and C.P. 29/291 were used to screen the collection.

Five 6-inch standard pots of each variety with two single-eye seed pieces were planted for each collection. The number of plants of each differential variety for inoculation with each collection varied from 5 to 10, depending upon germination.

The test plants were inoculated when 7 to 9 inches tall. They received applications of nitrogen 3 days prior to and about 1 week after inoculation, along with frequent watering, to keep them in a condition of rapid growth conducive to quick and clear symptom expression. A drop of juice from young leaf material was placed deep in the whorl of unfolding leaves. A thin steel insect-mounting pin was thrust repeatedly through the infectious juice and enclosing leaf tissues (10). The inoculated plants were grown in the greenhouse interspersed with uninoculated check plants. No check plants developed mosaic. Observations on mosaic type were made 6 to 8 weeks after inoculation. The system of classification used in Louisiana (15) was followed.

Selected collections were further tested on Co. 281. The commercial varieties M. 336, H. 328560, B. 37161, B. 34104, and B.H. 10(12) were inoculated with samples of all types of mosaic found to determine whether they had value as differential hosts.

RESULTS

IDENTIFICATION OF STRAINS

Most of the collections were grouped into strains A, B, and D, as described by Summers. The scope of this work was exploratory, extensive rather than intensive. Identification of strains by symptoms alone is somewhat subjective. Gradations and variations occur in a large number of collections. Broad limits of distinction were used. More precise techniques and more differentials might have resolved the collections into a greater number of groupings.

Strain A caused a mild mottling on the leaves of C.P. 31/294, with no necrosis, and only rarely a few chlorotic lesions. It did not stimulate tiller formation, was moderately stunting, and was easily transmitted.

Strain B formed many fine, elongate, strongly chlorotic-to-white lesions on leaves of C.P. 31/294, a variable amount of reddish necrosis which was seldom severe, caused moderate to severe stunting, and frequently produced excessive tillering. When healthy plants of the same age had no tillers, many of those infected with strain B would have 5 to 6. Some plants died. In general the internodes of severely affected plants were so shortened that the leaves appeared to rise immediately above one another. This type was highly infectious.

Strain D was most easily distinguished about 6 weeks after inoculation. Lesions apparently devoid of chlorophyll, longer and fewer in number than in type B, typified this strain. The background green or 'unaffected' leaf tissue was darker than that of healthy plants, resulting in a strong contrast between the whitish lesions and surrounding tissues. A variable amount of reddish-purple necrosis occurred with some collections, and tiller formation was moderately stimulated in a few. It was only poorly to moderately infectious. What was a clear type-D collection would frequently undergo a deterioration into a 'mixture' more like type A after 2 or more months on C.P. 31/294. This instability of strain D on C.P. 31/294 has been observed elsewhere (2). The Puerto Rican collections of strain D seemed less virulent than those of continental United States.

Leaf-sheath blotches were formed in variable degree on C.P. 29/291 in all but two collections. One formed type-B lesions on C.P. 31/294 and thus would correspond to Summers' strain G, and the other was an A on C.P. 31/294, making it an undescribed type. A variation in strain A was noted, in that a few collections brought an excessive expansion of the leaf blade near its junction with the sheath, folding troughlike upwards, with more severe stunting. These anomalies were not studied further as they were rare occurrences. No type-C lesions were observed on any inoculations to Co. 281. None of the commercial varieties used showed differential symptoms.

TABLE 1.—*Strains of mosaic observed on C.P. 31/294 and C.P. 29/291 approximately 60 days after inoculation*[1]

Origin of collection by locality and variety	Strain identification				Total
	A	B	D	Unidentified	
Locality:					
Yabucoa	0	29	5	3	37
Humacao	3	7	2	2	14
Naguabo	0	0	1	0	1
Ceiba	0	4	3	0	7
Fajardo	0	1	0	0	1
Juncos	2	1	1	0	4
San Lorenzo	0	0	3	0	3
Gurabo	0	3	6	0	9
Caguas	1	7	5	6	19
Cayey	0	0	1	0	1
Patillas	2	4	0	0	6
Arroyo	1	3	0	0	4
Aguirre	2	7	2	2	13
Cortada	5	6	5	3	19
Mercedita	5	23	3	0	31
Tallaboa	0	3	0	0	3
Hormigueros	0	7	0	0	7
Añasco	0	2	1	0	3
Coloso (all P.O.J. 36)	0	7	0	0	7
Moca (all P.O.J. 36)	0	19	0	0	19
Hatillo (all D. 1135)	10	12	3	0	25
Manatí	0	3	2	2	7
Vega Alta	0	0	1	0	1
Loiza	0	3	0	0	3
Total	31	151	44	18	244
Variety:					
B. 34104	8	33	12	8	61
B.H. 10(12)	4	28	6	3	41
B. 37161	5	12	13	2	32
M. 336	1	21	7	1	30
P.O.J. 36	0	29	0	0	29
D. 1135	10	12	3	0	25
B. 4098	0	7	1	0	8
B. 41211	3	3	2	0	8
Unknown (Gurabo)	0	3	0	2	5
H. 328560	0	2	0	1	3
P.O.J. 2878	0	1	0	0	1
Total	31	151	44	18	244

[1] 86 collections studied Feb.–May, 1953, and 158 studied Aug.–Dec., 1953.

OCCURRENCE OF STRAINS A, B, AND D

Geographic distribution of the strains was more or less random, in contrast to the well-marked distribution found in Louisiana (15). The small area of Puerto Rico with its free interchange of seed cane may contribute to this situation. Vector preferences might also influence strain distribution. There seemed to be a greater concentration of strain D in the Inland area about Caguas, Gurabo, and San Lorenzo (table 1). In most places strain B predominated, but all three strains were well represented at Cortada.

Strain B was most abundant in the susceptible commercial varieties B.H. 10(12), B. 34104, and M. 336, while in B. 37161 strain D was equally well represented (fig. 1). P.O.J. 36 and D. 1135, no longer commercial canes

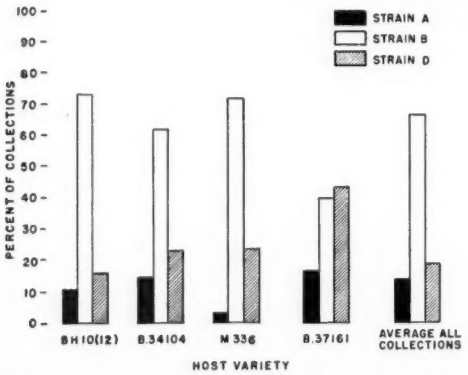

FIG. 1.—Distribution of strains of the mosaic virus in major varieties in Puerto Rico, 1952–53.

TABLE 2.—*Influence of source (host variety) of the mosaic virus (strain B) upon virulence and variability of collections judged by their effect on C.P. 31/294*

Variety	Collections compared	Mean height,[1]	Variance	Standard deviation	Coefficient of variation
	Number	*Inches*			*Percent*
B. 37161	5	41.5	48.35	6.95	16.7
B.H. 10(12)	17	40.4	23.94	4.89	12.1
B. 34104	11	38.7	20.98	4.58	11.8
M. 336	19	38.1	32.14	5.67	14.9
P.O.J. 36	20	34.8[2]	8.09	2.84	8.2

[1] Plant height = ground line to tip of longest leaf.

[2] The collections from P.O.J. 36 shortened C.P. 31/294 in comparison with those from M. 336 and B. 34104 at the 5-percent level of significance, and from B.H. 10(12) and B. 37161 at the 1-percent level.

were found infected and growing in isolation from new sources of mosaic as remnant stools in large areas of highly resistant canes. They are of greatest interest as historical specimens. Strains A, B, and D were recovered from D. 1135, and only strain B from P.O.J. 36.

Strain B makes up the bulk of the mosaic in Puerto Rico at the present time, with A and D present to a lesser extent (table 1). Considerable variability was observed among the 151 collections of strain B. The accessions

TABLE 3.—*Composite reaction of varieties of sugarcane to inoculation with mosaic virus strains A, B, and D, by the Matz method*

Variety[1]	Plants inoculated	Plants infected
	Number	*Percent*
B. 4098	34	94
B. 34104	114	92
B. 41211	34	91
B.H. 10(12)	114	89
B. 40116	26	81
M. 336	96	77
B. 40105	27	70
H. 328560	103	60
B. 37161	101	59
M. 341	37	51
P.R. 968	28	46
H. 371933	16	44
M. 32-134[1]	31	29
P.R. 970	24	25
Co. 421	29	21
P.O.J. 2725	32	19
P.R. 967	24	13
P.R. 969	37	8
P.R. 902	27	7
P.R. 907	30	7
P.R. 999	29	7
B. 41227	30	3
P.R. 903	31	3
P.P.Q.K.	30	0
B. 4362	35	0
M. 28	29	0
M. 275	30	0
M. 317	37	0
M. 338	27	0
P.R. 905	35	0
P.R. 1000	20	0
P.O.J. 2878	34	0

[1] M. 32-134 is a variety of Mauritius. All other M. varieties are from Mayagüez, P.R. B = Barbados; C.P. = Canal Point; H. = Hawaii; Co. = Coimbatore; P.O.J. = Proefstation Oost Java; P.R. = Puerto Rico (Río Piedras).

TABLE 4.—*Field observations of mosaic on 5 commercial varieties of sugarcane, with inoculation results by the Matz and Seín methods being compared*

Variety	Mosaic observed in commercial fields in Puerto Rico, Aug.–Sept. 1952			Mosaic induced by inoculation					
				Results of inoculation by Matz method			Results of inoculation by Seín method		
	Fields observed	Highest infection found	Average infection in all fields observed	Plants inoculated	Plants infected		Plants inoculated	Plants infected	
	Number	*Percent*	*Percent*	*Number*	*Number*	*Percent*	*Number*	*Number*	*Percent*
B. 34104	19	95	38	114	105	92	92	64	69
B.H. 10(12)	7	64	17	114	101	89	95	57	60
B. 37161[1]	14	8	2	101	60	59	96	33	34
M. 336[1]	17	3	0.2	96	74	77	101	35	35
H. 328560	10	5	1	103	62	60	110	6	5

[1] Since the time of this survey higher field infections have been observed on B. 37161 and M. 336. Allowing for subsequent untabulated observations, the proper order of field susceptibility would be B. 34104, B.H. 10(12), B. 37161, and M. 336, with H. 328560 being quite resistant.

from the commercial canes seemed more variable and, on the average, less virulent on C.P. 31/294 than those collected from D. 1135 and P.O.J. 36, and calculations[3] confirmed this relationship (table 2).

INOCULATION EXPERIMENTS ON VARIOUS VARIETIES

Several varieties were inoculated by the Matz method (10). This method of varietal testing was severe (table 3), as high percentages of infection were obtained in known susceptible varieties. Inoculation by this method was rapid and easily performed. Strain A was most infectious, B intermediate, and D least, with 59, 50, and 34 percent, respectively, of the plants that were inoculated becoming infected.

The Seín method (12) was given a small trial. It was less severe than the Matz method (table 4), and results were better correlated with observations of varietal susceptibility in the field. As in the Matz method, strain A was most infectious (66 percent), B intermediate (32 percent), and D least infectious (19 percent). The Seín method was comparatively laborious and slow.

DISCUSSION

The major strains of mosaic in Puerto Rico correspond closely to strains already described from continental United States. This indicates a degree

[3] The inoculations were made over a period of time, and statistical treatment removing this effect was made by Mr. I. Bangdiwala.

of basic stability in the mosaic virus, as the differences in climate and host varieties did not effect any major transformation in virus strains probably of the same origin. It may indicate that, although infinite minor variations occur within strains, there are fairly stable types adapted to widespread existence under field conditions, and that there is little danger of rapid development of new and devastating types as occurs in many other pathogens. The relative stability of the virus is supported by the continued success of Kassoer as a source of resistance. Continued care in the introduction of canes and closely related grasses should be practised, as not all known strains were found in Puerto Rico.

The mosaic collections on D. 1135 and P.O.J. 36 are of interest in that they allow historical deductions. The infected D. 1135 has grown continuously near Hatillo[4] for over 30 years, completely surrounded by resistant canes and free from any recent source of mosaic. The recovery of strains A, B, and D from this source indicates that these three strains were established on the Island many years ago, and that no other strain has been established on any scale since.

P.O.J. 36 can also be traced back several years[5] in isolation from new sources of mosaic. Only B was obtained from this cane. Matz (11) stated that P.O.J. 36 was one of the first mosaic-infected canes introduced into Puerto Rico from Java by way of Tucuman, Argentina. If the original seed was infected it is possible through protective exclusion (6) and failure to recover, that this mosaic has remained the same since its introduction. P.O.J. 36 could have given the dissemination of strain B considerable impetus.

The recent discovery of mosaic on M. 336 (4), a variety long considered resistant, led to the hypothesis that a new strain of mosaic might have developed. Juice taken from diseased D. 1135 and P.O.J. 36 and inoculated directly into M. 336 was highly infectious on this variety, indicating that M. 336 had previously escaped infection, though its infection required no change in the virus. The comparative uniformity and virulence of collections of strain B from P.O.J. 36 and D. 1135 on C.P. 31/294 suggests that the isolation of these canes has perpetuated a single type while the other varieties have been infected by representatives of strain B of diverse origins, or that strain B has been modified in the other varieties and wider environmental conditions sampled in the commercial canes, generally toward less virulent types.

[4] Mr. Rudolph Zequeira provided the history of these collections and assisted in the field of observations.

[5] P.O.J. 36 was collected on the west end of the Island, mostly at Coloso and Moca. Thanks are due to Mr. Alberto Esteves and Dr. J. B. Nolla for their assistance in collecting this cane.

Assuming B.H. 10(12) was the major reservoir of inoculum, and that B. 34104, M. 336, and B. 37161 were infected from that source, B. 34104 and M. 336 were similar to B.H. 10(12) in reaction to strains, as they have not substantially changed the relative abundance of A, B, or D from that found in B.H. 10(12). B. 37161, however, being exposed to the same inoculum, has altered the situation in that D is as abundant as B in that variety. B. 37161 apparently possesses some resistance to strain B, a big advantage when that is the prevalent strain. Strain D will tend to increase in B. 37161, if it is not kept free from mosaic, and when this preferred strain is sufficiently abundant, mosaic may spread as rapidly in it as it did in B. 34104. This possibility should encourage growers to take all possible precautions to keep this valuable cane free from mosaic.

Mechanical transmission has certain limitations in determining the 'field reaction' of varieties exposed to an epidemic. Both Matz' and Seín's methods gave high infections on the susceptible canes B. 34104 and B.H. 10(12). Matz' method, however, gave 60-percent infection on H. 328560, a variety that to date has taken very little mosaic in the field. By Seín's method this variety was only 5-percent infected, and some resistance was indicated in B. 37161 and M. 336. As in Hawaii (9), fairly good correlation with observed field reaction was obtained by Seín's method. Matz' method was too severe to show gradations in susceptibility which had practical importance. P. R. 980 was observed with a moderate infection in a small field adjacent to diseased B. 34104, and P. R. 975 is susceptible when inoculated by the Matz method, but their field reaction to mosaic is not yet known. They should be propagated with caution where they will be exposed to mosaic.

Strain A was most infectious by both methods of mechanical transmission, while B predominated in the field. Possibly the major vector or vectors of Puerto Rico transmit strain B more efficiently. It is important in planning programs of progeny testing to keep in mind that A was most easily transmitted mechanically, B intermediate, and strain D least transmissible.

SUMMARY

Three strains of sugarcane mosaic, A, B, and D, described in Louisiana, were found to make up the bulk of the collections of the sugarcane mosaic virus in Puerto Rico. Strain B was most prevalent. It was the major strain found on B.H. 10(12), B. 34104, and M. 336. Strain D was equally abundant on B. 37161. B. 37161 showed some resistance to mosaic in the field as compared with B. 34104. This may be due to some resistance to strain B. If B. 37161 is not kept free of mosaic, the preferred strain D may in-

crease in it and render it more susceptible in the field. No marked geographic pattern of strain distribution was observed.

Mechanical transmission of mosaic by the Seín method gave a better correlation with field reaction of varieties than did transmission by the Matz method. Strain A was most easily transmitted mechanically, while in the field strain B predominated in most varieties. Therefore, the vectors of Puerto Rico may be more efficient transmitters of strain B than of A.

RESUMEN

Tres cepas del mosaico de la caña de azúcar, A, B y D, descritas en Louisiana, se encontraron que comprendían el grueso de las colecciones del virus del mosaico en Puerto Rico. La cepa B fué la que prevaleció más. Fué la cepa encontrada con mayor frecuencia en las variedades B. H. 10(12), B. 34104, y M. 336. En la variedad B. 37161 la cepa D fué igualmente abundante. La B. 37161 demostró cierta resistencia al mosaico en el campo, comparada con la B. 34104. Puede que esto se deba a cierta resistencia al mosaico producido por la cepa B. Si la B. 37161 no se conserva libre del mosaico, la cepa preferida D puede aumentarlo en la variedad y hacerla más susceptible en el campo. No se observó un marcado patrón geográfico en la distribución de la cepa.

La trasmisión mecánica del mosaico, según el método Seín, dió una mejor correlación en las variedades en el campo que el método Matz. La cepa A pudo trasmitirse mecánicamente con mayor facilidad, mientras que en el campo la cepa B predominó en la mayor parte de las variedades, por lo tanto, puede que los vectores de Puerto Rico sean trasmisores más eficientes de la cepa B que de la A.

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Relationship between Chromosome Number and Stomata Size in Certain Pineapple Varieties

Alicia R. de Hernández[1]

INTRODUCTION

The pineapple, (*Ananas comosus* (L.) Merr.) is one of the most promising crops for Puerto Rico. At present, it is the third largest of all export crops, being preceded only by sugarcane. In Puerto Rico its average annual cost of production per acre may run as high as $500, and it produces a gross income per acre greater than most other crops (8)[2].

The main commercial variety planted in the Island is Red Spanish. This variety produces oblong fruit of firm texture, medium size, and with an average weight of 2 to 5 pounds. This variety has been exported to the United States for about 30 years. About 90 percent of the total area in the Island devoted to pineapple is planted to Red Spanish, 8 percent to Smooth Cayenne, and 2 percent to Cabezona.

Smooth Cayenne, the commercial variety of Hawaii, was planted for the first time in Puerto Rico in experiments carried on during 1910 (4). At present, it is planted in small areas on the northern coast. The fruit of this variety is of good quality, somewhat oblong in shape, medium to large in size, and weighs from 5 to 8 pounds.

Cabezona is the third variety of importance in the Island. The fruit of this variety is quite large, sometimes weighing as much as 12 to 15 pounds. Because its fruit is soft and juicy the Cabezona is not suitable for exportation and is consumed locally.

Two other pineapple varieties are of minor economic importance in Puerto Rico, the Negrita and Pan de Azúcar, both of which are used for local consumption only. Negrita is grown in the coffee area, and its fruit is somewhat elongated in form. Pan de Azúcar produces fruit of excellent taste, and similar in shape to those of Negrita. It is commonly found growing sparingly along the coastal regions of the Island.

During the fiscal year 1949–50, the area under pineapple cultivation on the Island was approximately 3,896 acres and the production from this area was 1,152,000 crates[3] (1). The best land for pineapple cultivation is

[1] Research Assistant in Cytology, Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P. R. The author is grateful to Mr. P. González-Ríos and Dr. H. E. Warmke for reading and correcting the text and to Mr. I. Bangdiwala for the statistical work.

[2] Numbers in parentheses refer to Literature Cited p. 204.

[3] Approximately 75 pounds per crate.

distributed along the northern coastal plains of Bayamón, Arecibo, and Manatí. There is also a small area in the central part of the Island around the towns of Corozal and Cidra where pineapples are cultivated. Small areas of pineapple are grown in the region of Lajas. (4)

The canned-pineapple exports from Puerto Rico to the United States during the fiscal year 1949–50, totaled about 19,520,21 pounds, with a value of $2,637,414. The average price per pound was 14 cents. (1)

The economic importance of pineapple as a crop for the Island is thus well established. However, the commercial varieties actually under cultivation in Puerto Rico are deficient in certain respects, such as low ratooning power and scant slip production. Because of this, a project is under way at this Station for the production of new varieties by means of hybridization.

OBJECTIVES

As an aid to the breeder in carrying on the above-mentioned project, careful cytological studies of chromosome numbers have been made. Chromosome counts in root tips are time-consuming because of the elaborate laboratory preparations required. If the relation between chromosome number and stomata size in pineapple found by Kerns and Collins (6) were applicable to the material used in Puerto Rico it would help in providing a simpler means for detecting polyploids in pineapple plants. If triploid and tetraploid plants could thus be distinguished, it would be as helpful as, and less time-consuming than actual chromosome counts.

The work here reported was performed to determine whether the above-mentioned relation between size of stomata and chromosome number in pineapple plants holds for the varieties available in Puerto Rico.

REVIEW OF THE LITERATURE

It has been found that many plant characters are correlated with chromosome number. Various measurements, such as pollen-grain size, cell size, size and frequency of stomata, have been used in studies of polyploidy. Kerns and Collins (6), working with pineapple material in Hawaii, found that the stomata and pollen of diploid plants were respectively smaller than those of tetraploids. They worked with the variety Smooth Cayenne.

Sax and Sax (10), making a comparison of diploid and tetraploid races of *Tradescantia canaliculata*, showed a high degree of correlation between chromosome number and size of stomata. Tetraploid races had larger stomata and larger pollen grains than diploids. Randolph (9) also found a relationship between polyploidy and cell size. He used stomata size to detect induced tetraploids in *Zea*.

In peppers, the haploid chromosome number was always associated with smaller stomata (3). Blakeslee (2) reported that artificially doubling the

chromosome number in hemp increased the stomata size. The size of stomata does not vary much between varieties of the same species having the same number of chromosomes. Nebel (7) stated that a difference of approximately 10 percent existed in the average length of stomata as between diploid and triploid apple varieties.

MATERIAL USED

Leaves of the following pineapple strains were studied:

Strain	*Common names*
(1) Red Spanish	Spanish, Black Spanish, Cuban Key Largo, Strawberry Scarlet Key, Largo, Havana
(2) Eleuthera	Common names unknown; strain brought from Florida for experimental use
(3) Hondureña	Strain brought from Honduras about 2 years ago for observation
(4) Amarelo Boituva	Brought from Brazil
(5) Pan de Azúcar	Sugar Loaf
(6) Natal	Natal Canning
(7) Smooth Cayenne	Kew, Giant Kew, Sarawak, Mexican white, Guatemala
(8) Golden Abachi	Abachi, Abacaxi, Abakka, Abbachi, Bacaxi
(9) Cabezona	Peurto Rico, Bullhead
(10) Inerme Paulista	Brought from Brazil
(11) Instituto Mayagüez	Brought from Venezuela[4]

PROCEDURE

Pineapple leaves were obtained from seedlings and from varieties in the Station collection. The material used was always freshly cut. The green leaves were of approximately the same size, stage of maturity, and position on the plant (second whorl from the spindle). All samples were ½ inch by 1½ inches, and were cut from approximately the same position of the selected leaf.

Stomata of pineapple leaves occur on both surfaces; however, those on the upper surface were found more satisfactory for study. Attempts were made to peel the epidermis of the leaves for the study of stomata by using the following materials: 5-percent butyl alcohol, 95-percent ethyl alcohol, methyl alcohol, acetone, and petroleum ether. None of these proved satisfactory, so the usual strip method was used exclusively.

The piece of leaf was peeled off with a scalpel along its coarse side until the transparent epidermis was sufficiently clear. The epidermis was mounted on a slide in a drop of distilled water and covered with a slip. Two-hundred and fifty observations were made for each of the 11 varieties

[4] The common names of the varieties mentioned above are those given by Johnson (5).

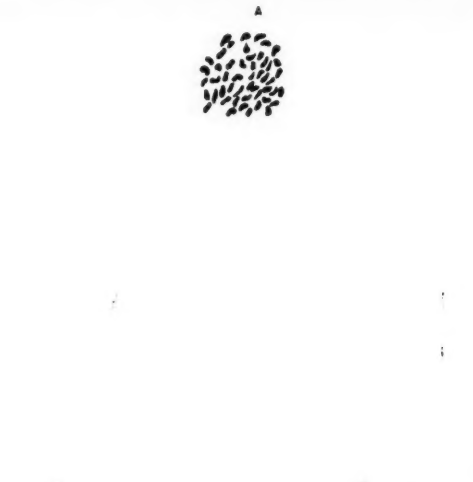

FIG. 1.—Somatic chromosomes of Red Spanish (A) and Cabezona (B and C) varieties of pineapple grown in Puerto Rico.

mentioned above. Fifty specimens of the stomatal apparatus[5] were measured on each plant.

A binocular microscope with a 20× hyperplane ocular and a 43× highpower objective was used. Measurements were made with the help of an ocular micrometer. Drawings of stomata and of chromosomes from root tips were made with the aid of a camera lucida.

RESULTS

Ten of the strains studied proved to be diploids with 50 somatic chromosomes (fig. 1, A). Average measurements for each variety and the standard error of the mean are shown in table 1.

The size of the stomata studied in 10 diploid strains and 1 triploid strain

[5] The term "stomatal apparatus" is used to indicate two guard cells and the included opening.

TABLE 1.—*Chromosome numbers and mean lengths and widths, and standard error of the mean of 10 pineapple strains studied*

Strain	Chromosome number	Mean length	Standard error of the mean	Mean width	Standard error of the mean
		Microns		*Microns*	
(1) Red Spanish	50	25.49	±0.098	22.18	±0.106
(2) Eleuthera	50	23.32	± .094	24.18	± .106
(3) Hondureña	50	24.51	± .091	24.16	± .105
(4) Pan de Azúcar	50	23.02	± .082	23.31	± .033
(5) Natal	50	23.07	± .082	22.17	± .095
(6) Smooth Cayenne	50	20.89	± .063	22.73	± .111
(7) Golden Abachi	50	24.32	± .083	22.59	± .122
(8) Inerme Paulista	50	22.59	± .083	23.73	± .100
(9) Instituto Mayagüez	50	23.90	± .095	22.54	± .100
(10) Amarelo Boituva	50	23.50	± .087	24.13	± .092
General diploid mean		23.46	± .028	23.16	± .033
Cabezona	75	27.88	± .097	26.84	± .113
Least significant difference:					
At the 5-percent point		0.18		0.22	
At the 1-percent point		.24		.29	

of pineapple shows that there is a significant difference between stomata size of diploids and triploids (fig. 2).

The variety Cabezona was the only one found with a chromosome number (75 somatic chromosomes, fig. 1, B and C) different from that of all the others. Its stomata were also greater in both length and width ($27.88 + 0.097 \times 26.84 + 0.113$) than those of the varieties (fig. 2, A).

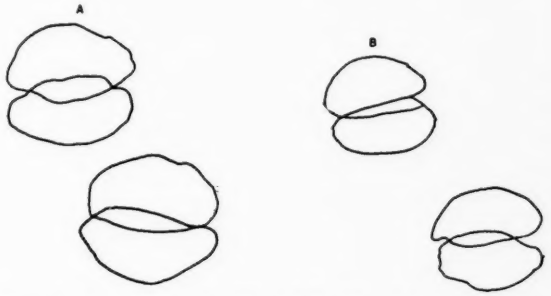

FIG. 2.—Stomata size of Cabezona (A) and Red Spanish (B) varieties of pineapple grown in Puerto Rico. The average size for Cabezona was 29.28 x 28.38 microns, and for the Red Spanish 23.07 x 22.89 microns.

SUMMARY

A study of the chromosome number as related to stomata size has been reported herein for certain varieties of pineapples grown in Puerto Rico. The diploid strains studied were: Red Spanish, Eleuthera, Hondureña, Pan de Azúcar, Amarelo Boituva, Natal, Smooth Cayenne, Golden Abachi, Inerme Paulista, and Instituto Mayagüez. The triploid strain was Cabezona. The average size of stomata in the diploid strains was found to be 23.46 x 23.16 microns. The stomata of the triploid strain averaged 27.88 x 26.84 microns. The difference in the size of the stomata of the diploid and triploid strains was found to be highly significant.

RESUMEN

Se informan aquí los resultados de un estudio sobre el número de cromosomas en la piña, en relación con el tamaño de las estómatas. Las variedades diploides estudiadas fueron: Española Roja, Eleuthera, Hondureña, Pan de Azúcar, Amarelo Boituva, Natal, Cayena Lisa, Golden Abachi, Inerme Paulista, e Instituto Mayagüez. La variedad triploide fué la Cabezona.

El tamaño promedio para las variedades diploide fué 23.46 x 23.16 micrones. Para la variedad triploide 27.88 x 26.84 micrones. La diferencia en cuanto al tamaño de las estómatas de las variedades diploide y triploide fué altamente significativa.

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Control of Factors Increasing the Preweaning Mortality of Swine in Puerto Rico

A. González-Chapel and Ismael Carlo[1]

THE PROBLEM

The losses caused by preweaning mortality of swine in the United States amount to several millions dollars a year. There is no way of estimating the monetary value of such losses in Puerto Rico, but it is certain that they are considerable.

According to Smith, (11)[2], the losses which occur among young pigs prior to weaning probably constitute the heaviest drain on profits the swine industry is forced to bear. He estimated these losses at about one-third of all the pigs born, including in the mortality pigs born dead. Dale, (6), stated that it is not unusual for 50 percent or more of the pigs to die during the first few days of life. Bagué (3) reported a mortality of 30.41 percent in the herds of the Puerto Rico Reconstruction Administration, although apparently still-born pigs were not included in this estimate.

Many factors are responsible for the preweaning mortality of swine, but the majority of the investigators agree that most of them are under the control of the farmer and thus are preventable.

It was thought that a careful study of the preweaning mortality of the pigs in the Puerto Rico Agricultural Experiment Station herd, with the classification of the causes of death and the analysis of the factors influencing the mortality, might serve as a basis for the preparation of individual programs by the swine producers of the Island to reduce their preweaning losses, and thus adopt a more efficient system of management.

PROCEDURE

This study covers 9 years, from 1940 to 1949, at the La Plata Animal Production Substation of the Puerto Rico Agricultural Experiment Station.

A total of 158 different sows kept in the herd during the period studied were considered. They included 69 Native, 54 Duroc Jersey, 12 F_1 Duroc x Native, 9 F_1 Landrace Large Black x Native, and 14 F_1 Landrace Large Black x Duroc sows.

These sows farrowed 382 litters which included 138 from the Duroc sows,

[1] Associate Animal Husbandman and Assistant Animal Husbandman, respectively, Agricultural Experiment Station, University of Puerto Rico, Río Piedras, P. R. The authors wish to express their appreciation to Dr. J. Rivera Anaya of this Station for his help in evaluating the causes of death of the pigs, and to J. I. Cabrera, also of the Station, for early assistance in the tabulation of data.

[2] Numbers in parentheses refer to Literature Cited p. 223–4.

184 from the Native sows, and 21 F_2 Duroc x Native, 18 F_2 Landrace Large Black x Native, and 21 F_2 Landrace Large Black x Duroc litters. A total of 3,841 pigs were produced in these litters of which 1,750 were from the Duroc sows, 1,487 from the Natives, 228 from the Duroc x Native, 173 Landrace Large Black x Native, and 203 Landrace Large Black x Duroc.

Records were made during the entire period of the number of pigs farrowed, the number weaned, the farrowing weights, and the distribution of mortality. Causes of death were included whenever the information was available.

Throughout the 9 years the same feeding program was followed, based mainly on concentrate feed imported from the United States.

DISTRIBUTION OF MORTALITY

The 382 litters produced during the period studied by the 158 sows of the different breeds and crossbreeds totaled 3,841 pigs. Of these, 2,469 were weaned, with a mortality, including farrowed dead pigs, of 35.72 percent. The average litter numbered 10.05 pigs of which 6.46 were weaned and 3.59 died before weaning. The distribution of the preweaning mortality is shown in table 1.

Table 1 shows that 70.26 percent of all the pigs that died before weaning were farrowed dead, or died within the first week after farrowing, and that 86.37 percent of all that died were farrowed dead or died within the first month after farrowing. Only 10.06 percent of the deaths occurred in the second month of the weaning period.

Weaver (13) stated that approximately one-half of all preweaning losses occur before the litter is 3 days old, and more than four-fifths by the time the pigs are 2 weeks of age.

TABLE 1.—*Distribution in time of the preweaning mortality of 1,372 pigs out of 3,841 farrowed*

Time of death	Number dead	Proportion of dead to total farrowed	Proportion of total dead
		Percent	*Percent*
Still-born	312	8.12	22.74
1st week	652	16.97	47.52
2nd week	119	3.10	8.68
3d week	63	1.64	4.59
4th week	39	1.02	2.84
5th–6th weeks	73	1.90	5.32
7th–8th weeks	65	1.69	4.74
Unknown	49	1.28	3.57
Total	1,372	35.72	100.00

TABLE 2.—*Causes of preweaning mortality among 322 litters of pigs farrowed by Duroc and Native sows*

Cause of death	Proportion of total farrowed	Proportion of dead
	Percent	*Percent*
Weak	12.82	37.32
Born dead	8.47	24.64
Killed by sows	5.04	14.66
Scours	1.51	4.40
Put to other sows	.80	2.34
Miscellaneous diseases	.37	1.08
Necro	.19	.54
Abnormal	.12	.36
Anemia	.09	.27
Unknown	4.94	14.39

CAUSES OF DEATH

Causes of death were ascertained for 322 litters farrowed by the Duroc and Native sows, which included 3,237 pigs with a preweaning mortality of 34.35 percent. The causes of death, insofar as they could be determined, are shown in table 2.

Deaths classified as caused by weakness, or of which the cause was unknown, probably included unidentified cases of anemia, starvation, smothering, worms, and pneumonia, although many were of pigs born weak constitutionally.

According to Smith (11) still-born pigs in the United States accounted for 5.2 percent of the total born, and trod-on pigs for 15 percent. In the Station herd more pigs were born dead but fewer were killed by the sows, probably because guard rails were available in the farrowing pens.

Still-birth and congenital weakness accounted for most of the deaths of weanling pigs in this herd. Weaver (13) suggested that pigs may be weak at farrowing time because of nutritional deficiency in the ration of the sow prior to farrowing. Madsen (9) stated that a deficiency of iodine in the ration of pregnant sows leads to the birth of weak offspring. The young pigs may be still-born or they may be born alive and die shortly afterward. However, it is more probable that in this herd the high fertility of the sows was at least a contributing factor for the many still-born and weak pigs produced.

Anemia is probably more prevalent in young pigs in Puerto Rico than is apparent from this study. Hamilton, et al. (8), regarded anemia as an important factor in the mortality of suckling pigs.

Among the classifiable diseases, scours was the main cause of death.

FACTORS INFLUENCING PREWEANING MORTALITY

Young pigs are subject to a variety of maladies caused mainly by faulty breeding, nutrition, and management practices. However, some factors indirectly affect the mortality by increasing the propensity of the pigs to fall prey to the different diseases which ultimately cause their death. To a certain extent these factors are also under the control of the farmer. The farrowing season, the breed, the age of the dam, the litter number of the sow the farrowing weight, and the size of the litter are included in the following discussion.

FARROWING SEASON

The effect of farrowing season on mortality was studied in the 322 litters farrowed by the Duroc and Native sows. Table 3 shows the distribution of the preweaning mortality in the different seasons.

The differences in total mortality were just on the level of statistical significance; there was a strong tendency for the summer litters to have lower preweaning mortality. The differences in mortality during the first week were highly significant; more pigs died during the first week in the spring season. The differences in the number of pigs killed by the sows were also highly significant; in autumn and winter the sows killed more pigs than in spring and summer. Summarizing, mortality was lower in the summer litters because the sows killed more pigs in autumn and winter, and more pigs died during the first week in the spring.

TABLE 3.—*Seasonal distribution of preweaning mortality in 322 litters of pigs farrowed by Duroc and Native sows*

Time or cause of death	Winter litters		Spring litters		Summer litters		Autumn litters	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Still-born	65	9.12	67	7.91	92	8.23	50	8.94
1st week	76	10.66	137	16.17	132	11.81	55	9.84
2nd week	21	2.95	24	2.83	26	2.33	15	2.68
3d week	14	1.96	13	1.54	11	.98	8	1.43
4th week	4	.56	6	.71	2	.18	11	1.97
5th–6th weeks	8	1.12	14	1.65	7	.63	7	1.25
7th–8th weeks	7	.98	18	2.13	10	.89	4	.72
Unknown	7	.98	4	.47	29	2.59	5	89
Killed by sows	41	5.75	30	3.54	43	3.84	49	8.77
Total dead	243	34.08	313	36.95	352	31.48	204	36.49
Total farrowed	713		847		1,118		559	

Hamilton, et al. (8), held that nutritional or milk anemia in suckling pigs is more prevalent in February and March litters than in those farrowed in the late spring, or summer, or fall.

A detailed study of the first-week deaths during the spring indicated, however, that most of them occurred in May, and that at least an important contributing cause was scours. In May 1946, at least 11 pigs with scours died during the first week. According to Dale (6), swine develop enteritis and scours almost entirely because of faulty nutrition and lack of proper housing, care, and sanitation. Although no records of rainfall are available for the period, it is possible that excessive rain made it difficult to keep the pens clean.

McDonald (10) observed that spring weather conditions in the United States are none too favorable for the little pigs. If the pigs are not kept dry and warm, scours may appear.

Bagué (3) concluded that, in La Plata, P. R., preweaning mortality was highest during December, January, and February, because of cold weather. He also suggested a relationship between the dry season and high mortality caused by scarcity of green grass. The dry season coincides with the winter months. This may explain the increased number of pigs killed by the sows during autumn and winter, as reported in this study.

BREED

Breeds differences in mortality were analyzed in two ways. A comparison was made between the Native and the Duroc sows, regardless of the boars mated to them. The effect of hybrid vigor was studied by comparing the litters produced by Duroc sows mated to Duroc boars and to boars of other breeds, and by the comparison of litters produced by Native sows mated to Native boars and to boars of other breeds.

The distribution in time of the mortality of the 184 litters farrowed by the Native sows and the 138 litters farrowed by the Duroc sows is shown in table 4. The pigs considered included 1,750 from the Native sows and 1,487 from the Duroc sows.

The Duroc sows farrowed litters averaging 11.1 pigs of which 7.1 were weaned and 4 died, or 63.9 percent of the pigs farrowed were weaned. The Native sows farrowed litters averaging 9.62 pigs of which 6.45 were weaned and 3.16 died, or 67 percent of the total pigs farrowed were weaned.

The differences in total mortality between the two breeds were not quite significant. However, there were significant differences in the number of pigs farrowed dead, deaths during the first week, and in the number of pigs killed by the sows. The Duroc sows farrowed more dead pigs and also killed more pigs than the Natives, but the latter lost more pigs during the first week.

TABLE 4.—*Distribution in time of preweaning mortality of 184 litters farrowed by Native, and 138 litters farrowed by Duroc sows*

Time or cause of death	Duroc		Native	
	Number	Percent	Number	Percent
Still-born	154	10.36	120	6.86
1st week	157	10.56	243	13.89
2nd week	46	3.09	40	2.29
3d week	21	1.41	25	1.43
4th week	15	1.01	8	.46
5th–6th weeks	16	1.08	20	1.14
7th–8th weeks	17	1.14	22	1.25
Unknown	9	.61	36	2.06
Killed by sows	101	6.79	62	3.54
Total	536	36.05	576	32.91

According to Aubel, et al. (2), there is a very definite relation between the ability of a sow to secrete milk and the number of pigs she is able to raise. It is possible that the Duroc sows could not provide milk for all their pigs because of the large litters. The larger litters might also be expected to cause more farrowed dead pigs among the Durocs. On the other hand, the Native pigs weighed less at farrowing, which would be a possible explanation for the large number of them that died during the first week.

In table 5 is shown the distribution in time and other data related to the mortality of 1,134 purebred Durocs, 136 Duroc x Tamworth, 59 Duroc x Native, and 158 Landrace Large Black x Duroc pigs.

The beneficial effect of hybrid vigor is attested by the fact that the crossbred litters had significantly lower mortality than the purebred Durocs. The heavy mortality of the Durocs was mainly attributable to the many still-born pigs in their litters. The crossbred litters were more vigorous and fewer pigs were farrowed dead.

The Tamworth x Duroc had lower mortality than the other crossbreds. The Landrace Large Black x Duroc was slightly better than the Duroc x Native. Significantly fewer Landrace Large Black x Duroc pigs were killed by the sows. This may have been because the weight of these pigs was better at birth. Proportionately fewer Tamworth x Duroc pigs died during the first week.

The distribution of the mortality of the Native and Native crossbreds is shown in table 6. Hybrid vigor was not as noticeable in the Native crossbred as in the Duroc crossbred litters. The simultaneous double-cross, Native x Duroc x Hampshire, and the Hampshire x Native had a significantly lower mortality than the Native and the other crossbreds. The

TABLE 5.—*Distribution in time of preweaning mortality of purebred and crossbred Duroc litters*

Time of death and other factors	Duroc		Tamworth x Duroc		Duroc × Native		Landrace Large Black × Duroc	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Still-born	133	11.63	7	5.15	3	5.08	11	6.96
1st week	125	11.02	7	5.15	7	11.86	18	11.39
2nd week	39	3.44	3	2.21	1	1.69	3	1.90
3d week	14	1.23	0	0	3	5.08	4	2.53
4th week	15	1.32	0	0	0	0	0	0
5th–6th weeks	13	1.15	0	0	1	1.69	2	1.27
7th–8th weeks	15	1.32	0	0	0	0	2	1.27
Unknown	5	.44	1	.74	0	0	3	1.90
Killed by sows	86	7.58	7	5.15	5	8.47	3	1.90
Total	445	39.24	25	18.38	20	33.90	46	29.11
Litter size	10.50		12.36		11.80		11.29	11.29
Weaned	6.38		10.09		7.80		8.00	8.00
Dead	4.12		2.27		4.00		3.29	3.29
Proportion weaned of total farrowed		60.8		81.6		66.1		70.8

Duroc x Native and the Native litters had a lower mortality than those of the Landrace Large Black x Native and the Tamworth x Native. The heavy mortality in the last two breeds occurred mainly during the first week.

The advantages of crossbreeding on several preweaning and postweaning characteristics of swine were reported for a similar group of pigs in Puerto Rico by A. González Chapel and J. I. Cabrera (7).

AGE OF DAM

The effect of the age of the dam on the mortality of the litters was studied separately in the Duroc and Native sows. Sows of unknown age were not included in the analysis. Table 7 show the information gathered for each breed.

The differences in total mortality were statistically significant. Pigs from sows that were 16 to 23 months old had the lowest mortality. The greatest mortality was among pigs from sows that were 48 months old or more. The average litter size of the 16- to 23-month age group was 8.13 pigs, the smallest among all the age groups. Members of a smaller litter have a better chance of survival and this may have been a contributing factor to the lower mortality shown by the progeny of the 16- to 23-month age group.

The differences in total mortality between the Duroc sows of different

TABLE 6.—*Distribution in time of preweaning mortality of purebred Native and Native crossbred litters*

Time of death and other factors	Native		Tamworth × Native		Duroc × Native		Landrace × Native		Hampshire × Native		Native × Duroc × Hampshire	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Still-born	70	7.34	6	4.91	14	7.14	15	7.97	11	7.43	1	0.99
1st week	110	11.53	22	18.03	23	11.73	31	16.48	10	6.75	16	15.84
2nd week	21	2.20	7	5.73	3	1.53	6	3.19	2	1.35	1	.99
3d week	16	1.68	3	2.45	2	1.02	3	1.59	0	0	0	0
4th week	9	.94	0	0	0	0	0	0	0	0	0	0
5–6th weeks	19	1.99	0	0	1	.51	0	0	0	0	0	0
7–8th weeks	17	1.78	5	4.09	1	.51	0	0	0	0	0	0
Unknown	2	.21	8	6.55	8	4.08	17	9.04	1	.67	0	0
Killed by sow	35	3.67	1	.81	9	4.59	2	1.06	9	6.08	3	2.97
Total	299	31.34	52	42.62	61	31.12	74	39.36	33	22.29	21	20.79
Litter size	9.09		11.09		10.32		9.89		9.87		8.42	
Weaned	6.24		6.36		7.11		6.00		7.67		6.67	
Dead	2.85		4.73		3.21		3.89		2.20		1.75	
Proportion weaned of total farrowed		68.65		57.35		68.90		60.67		77.71		79.22

TABLE 7.—*Effect of age of dam in months on the distribution in time of preweaning mortality of Native and of Duroc pigs*

Time of death and other factors	Offspring of sows aged (in months)—									
	15 or less		16 to 23		24 to 35		36 to 47		48 or more	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Native pigs										
Still-born	10	4.61	9	3.69	27	5.57	24	11.88	14	8.19
1st week	23	10.60	32	13.11	80	16.49	26	12.87	36	21.05
2nd–4th week	14	5.45	11	4.51	19	3.92	9	4.46	9	5.26
5th–8th weeks	16	7.37	4	1.64	11	2.27	3	1.49	6	3.51
Unknown	6	3.77	2	.82	17	3.51	3	1.49	7	4.09
Killed by sows	5	2.30	7	2.87	17	3.51	6	2.97	4	2.34
Total	74	34.10	65	26.64	171	35.26	71	35.15	76	44.44
Duroc pigs										
Still-born	29	14.15	18	6.55	28	10.39	39	18.86	18	14.40
1st week	13	6.34	25	9.09	44	16.18	18	8.61	15	12.00
2nd–4th week	12	5.85	12	4.36	13	4.78	11	5.26	4	3.20
5th–8th weeks	14	6.83	7	2.55	1	.37	1	.48	0	0
Unknown	1	.48	3	1.09	2	.73	2	.95	1	.80
Killed by sows	8	3.90	10	3.64	17	6.25	11	5.26	9	7.20
Total	77	37.56	75	27.27	105	38.60	82	39.23	47	37.60
Total farrowed	205		275		272		209		125	

ages were statistically significant. The lowest mortality was also found in the progeny of sows aged 16 to 23 months. The average litter size in this group was again smaller than that of the older groups.

In both the Natives and the Durocs the differences in the mortality between progeny from sows of different ages during the fifth- to the eighth-week period were highly significant. The sows aged 15 months or less lost more pigs during that time than those of other age groups. They also farrowed more dead pigs than the sows 16 to 23 months of age. The heavier mortality of the pigs from sows 24 to 35 months old as compared with that of those from sows 16 to 23 months old occurred mainly because more pigs died during the first week and more pigs were farrowed dead. Sows in the last two age groups farrowed many more dead pigs than sows 16 to 23 months old.

The differences in pigs killed by sows in different age groups were not significant.

LITTER NUMBER

The effect of the litter number on preweaning mortality was studied up to and including the sixth litters of the sows. The data for the Durocs and the Native sows were analyzed separately. Table 8 presents the figures gathered for both the Native and the Duroc sows.

There were 69 Native first litters with an average of 8.14 pigs farrowed and 5.55 weaned; 42 second litters with 9.76 pigs farrowed and 7.17 weaned; 49 third and fourth litters with 10.65 pigs farrowed and 7.08 weaned; and 22 fifth and sixth litters with 10.77 pigs farrowed and 5.95 weaned.

The differences in total mortality between the litters were statistically

TABLE 8.—*Effect of litter number on the distribution in time of preweaning mortality of Native and of Duroc pigs*

Time of death and other factors	Results from litter No.							
	1		2		3–4		5–6	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Native pigs								
Still-born	29	5.16	16	3.90	47	9.00	24	10.13
1st week	70	12.46	55	13.41	67	12.84	49	20.68
2nd–4th week	22	3.91	15	3.66	18	3.45	18	7.59
5th–8th week	22	3.91	4	.98	11	2.11	5	2.11
Unknown	13	2.31	5	1.22	15	2.87	3	1.27
Killed by sows	23	4.09	14	3.41	17	3.26	7	2.95
Total	179	31.85	109	26.59	175	33.52	106	44.73
Total farrowed	562		410		522		237	
Duroc pigs								
Still-born	56	10.22	23	6.46	46	11.41	23	15.75
1st week	47	8.58	42	11.80	47	11.66	19	13.01
2nd–4th week	46	8.39	14	3.93	15	3.72	7	4.79
5th–8th week	25	4.56	5	1.40	3	.74	0	0
Unknown	4	.73	2	.56	2	.50	1	.68
Killed by sows	33	6.02	19	5.34	34	8.44	13	8.90
Total	211	38.50	105	29.49	147	36.48	63	43.15
Total farrowed	548		356		403		146	

TABLE 9.—*Effect of birth weight on the distribution in time of preweaning mortality of Native and Duroc pigs*

Time of death and other factors	Birth weight of—	
	Natives	Durocs
	Pounds	*Pounds*
Still-born	1.50	1.76
1st week	1.60	1.97
2nd week	1.74	2.28
3d week	2.07	2.45
4th week	1.81	2.50
5th–6th weeks	1.92	2.33
7th–8th weeks	2.01	2.42
Unknown	1.76	2.21
Killed by sows	1.80	2.31

significant. The mortality decreased from the first to the second litter and then increased again, reaching a maximum in the fifth and sixth litters. The differences in the number of farrowed dead pigs were also significant. Farrowed dead pigs were more common from the third to the sixth litter. The differences in the number of deaths during the first week were significant. In the fifth and sixth litters more pigs died during the first week. There were also significant differences in the mortality during the fifth- to eighth-week period. During that period fewer pigs died in the second litters.

The data on the Duroc sows included 55 litters with 9.96 pigs farrowed and 6.13 weaned; 33 second litters with 10.79 pigs farrowed and 7.61 weaned; 35 third and fourth litters with 11.51 pigs farrowed and 7.31 weaned; and 12 fifth and sixth litters with 12.17 pigs farrowed and 6.92 weaned.

The differences in total mortality between the litters were significant. As was the case with the Native pigs, the mortality decreased from the first to the second litters and increased again, with maximum mortality in the fifth and sixth litters. Fewer still-born pigs were found in the second litter and more in the fifth and sixth litters. More pigs died during the fifth-to-eighth-week period in the first litters.

The effect of the litter number on the mortality was similar to the effect of the age of the dam.

FARROWING WEIGHT

The average birth-weight of the pigs that died before weaning is shown in table 9 for the Native and Duroc sows.

For the Natives the average farrowing weight was 2.04 pounds and the average farrowing weight of the pigs that were weaned was 2.25 pounds.

The average birth-weight of the pigs that died, regardless of the time of death, was smaller than the average birth-weight of the pigs that were weaned.

For the Durocs the average farrowing weight was 2.44 pounds and the average farrowing weight of the pigs that were weaned was 2.66 pounds. Among the Durocs, as among the Natives, the pigs that died weighed less at birth than the pigs that were weaned. In most cases the birth-weight of the pigs that subsequently died was smaller than the average farrowing weight of the pigs.

Russell, cited by Smith (11), found a relation between the birth-weight and the percentage born dead and the percentage weaned.

The regression of mortality on the farrowing weight is shown in figure 1 both for the Natives and the Durocs. As farrowing weight decreased mortality increased.

SIZE OF LITTER

The effect of the litter size on preweaning mortality is shown in table 10 for the Native sows. A total of 43 litters composed of 7 pigs or less, 96 litters of 8 to 11 pigs, and 45 litters of 12 or more pigs were included in the analysis.

There were significant differences in mortality. The litters of 12 or more pigs suffered greater mortality than the smaller litters. During the first week fewer pigs died in litters of seven or less.

The information for the Duroc sows is also given in table 10 and includes

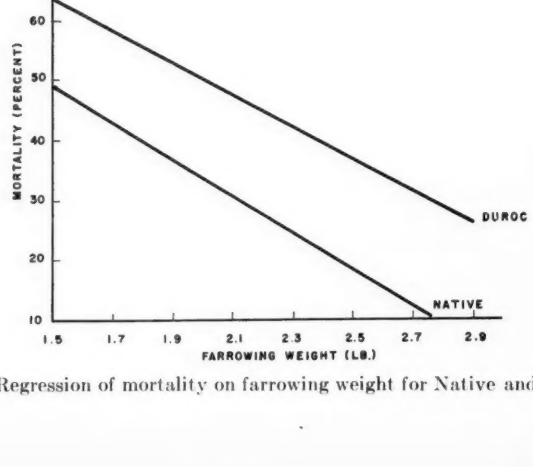

FIG. 1.—Regression of mortality on farrowing weight for Native and Duroc pigs.

TABLE 10.—*Effect of litter size on the distribution in time of preweaning mortality of Native and of Duroc pigs*

Time of death and other factors	Results for litters of—					
	7 or less		8 to 11		12 or more	
	Number	Percent	Number	Percent	Number	Percent
Native pigs						
Still-born	18	7.89	55	5.99	47	7.68
1st week	16	7.02	99	10.78	128	21.19
2nd–4th weeks	8	3.51	31	3.38	34	5.63
5th–8th weeks	7	3.07	24	2.61	11	1.82
Unknown	5	2.19	9	.98	22	3.64
Killed by sows	5	2.19	41	4.47	16	2.65
Total	59	25.88	259	28.21	258	42.72
Total farrowed	228		918		604	
Duroc pigs						
Still-born	12	12.24	46	7.85	96	11.96
1st week	6	6.12	45	7.68	106	13.20
2nd–4th weeks	2	2.04	34	5.80	46	5.73
5th–8th weeks	4	4.08	20	3.41	9	1.12
Unknown	0	0	4	.68	5	.62
Killed by sows	10	10.20	33	5.63	58	7.22
Total	34	34.69	182	31.06	320	39.85
Total farrowed	98		586		803	

17 litters of 7 pigs or less, 60 litters of 8 to 11 pigs, and 61 litters of 12 or more pigs.

The differences in mortality were statistically significant. As in the Natives, the litters of 12 or more pigs suffered greater mortality than the smaller litters.

There were significant differences in the mortality from the fifth to the eighth week. In that period lower mortality was observed in litters of 12 pigs or more, than in the other groups; and there was also lower mortality in the litters of 8 to 11 pigs than in those of 7 or less. The same trend, although not significant, was observed in the Natives. Large litters are thus subject to heavier mortality because of more deaths during the first 4 weeks.

González-Chapel and Cabrera (7), with a similar group of pigs, found that individual farrowing weight decreased as size of litter increased. This

may be the main cause of the heavier mortality of the larger litters. Carmichael, cited by Smith, (11) reported no greater loss in the larger litters, up to 10, than in the smaller ones. When the number of pigs to the litter exceeded 10, however, there was a regular tendency, both absolutely and relatively, for the number farrowed dead or immature to increase with the increased size of the litter. Wenck, also cited by Smith, (11), found that pigs farrowed in litters of 7 were most likely to survive.

CORRELATION BETWEEN FACTORS

The interrelationship between some of the factors influencing the preweaning mortality was studied using the data obtained from 68 purebred Duroc litters and 82 purebred Native litters on which complete information was available.

The factors considered were age, litter number, size of litter, and farrowing weight. The relative importance of the different factors in respect to mortality by means of the multiple regression coefficients is shown in the following tabulation:

	Coefficients	
Factors	*Duroc litters*	*Native litters*
Age and litter number	0.0721	0.0204
Age and litter number and litter size	.2650	.1587
Age and litter number and litter size and farrowing weight	.4809**	.4793**

In both the Natives and the Durocs the regression of the four factors was statistically significant, but the significance was mainly caused by the effect of the farrowing weight. The size of the litter was of some importance but it was not significant. The age and the litter number were of minor importance in the regression.

The following tabulation gives the correlations between the different factors studied and their correlation with the mortality:

	Correlations	
Factors	*Duroc litters*	*Native litters*
Age with mortality	−0.0171	0.0096
Litter number with mortality	− .0669	− .0093
Size of litter with mortality	.2067	.1573
Farrowing weight with mortality	− .4286**	− .4729**
Age with litter number	.8741**	.5730**
Age with litter size	.1871	.1564
Age with farrowing weight	.00004	.0315
Litter number with litter size	.3773*	.1837

Litter number with farrowing weight	— .1016	.1091
Litter size with farrowing weight	— .2492*	— .1670

Age and litter number are highly correlated. Naturally, the number of litters farrowed by a sow increases with her age. The litter number has a significant effect on the litter size as shown by the correlation between these two factors in the Duroc litters. The regression of litter size on litter number is given in figure 2. The litter size in the Durocs increased with the litter number up to and including the sixth litter. After the sixth litter the litter size decreased with the litter number.

Anderson (1), stated that best prolificacy was obtained in the sixth or seventh litter. Smith (11), reported data from 10 college and experiment station herds showing a curve similar to that reported here, but concluded that a sow may be expected to produce an increasing number of pigs up to and including her fourth litter, and that from the fourth litter on, she may be expected to produce a decreasing number with each succeeding litter. The regression line for the Native litters confirms this statement.

The litter size has a significant effect on the farrowing weight of the pigs as is shown by the correlation found in the Duroc litters. The regression of farrowing weight on the litter size in this work is shown in figure 3. The average farrowing weight of the litters decreased as the litter size increased.

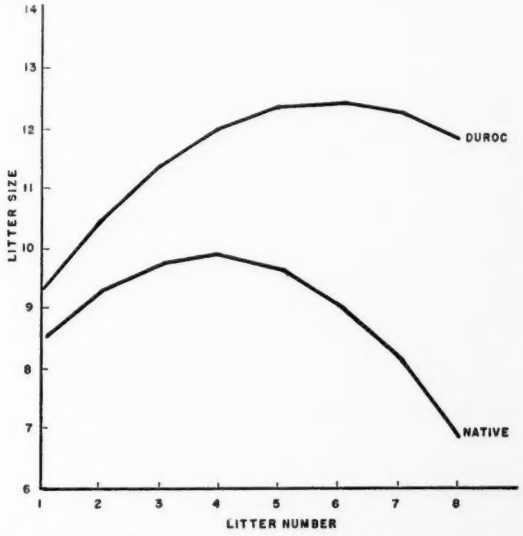

FIG. 2.—Regression of litter number for Native and Duroc pigs.

Carmichael and Rice (5), reported that as the number of pigs in the litter increased, the size of the individuals quite regularly decreased. González-Chapel and Cabrera (7) with a similar group of pigs in Puerto Rico, reported a significant correlation of -0.1790 between litter size and farrowing weight.

Thus, age and litter number have an effect on the litter size. The litter size influences the farrowing weight and the farrowing weight is very important in connection with the mortality. All four factors, therefore, have to be considered when developing a program for reducing the preweaning mortality.

This interrelationship of the factors studied also illustrates the reasons for the important relations found between each individual factor and the mortality. In the age groups, sows of 16 to 23 months, both of the Duroc and the Native breeds, farrowed fewer pigs than sows from 24 to 48 months old, and mortality was consequently reduced. As to the position of the litter, the second litters were smaller than the third to the sixth litters and consequently had lower mortality. The farrowing weight was probably the main cause of the heavier mortality of litters of 12 or more pigs.

CONCLUSIONS AND RECOMMENDATIONS

The average preweaning mortality of all litters considered in this study was approximately 35 percent of the total pigs farrowed. If due considera-

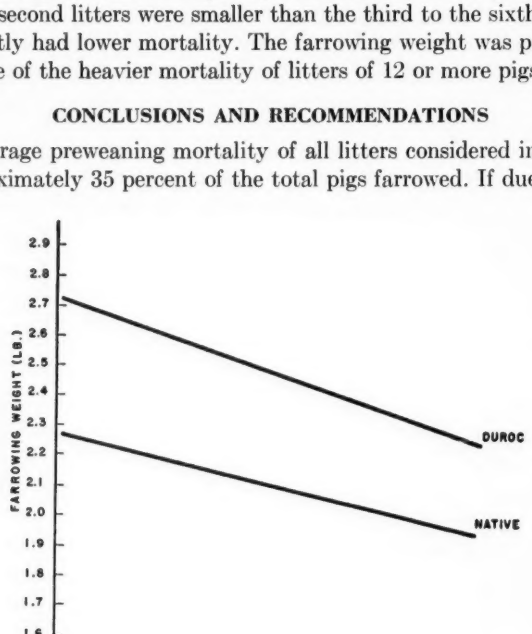

FIG. 3.—Regression of the farrowing weight on the litter size for Native and Duroc pigs.

tion is given to the fact that the herd studied was probably above average in the Island in respect to management, the conclusion is inescapable that the loss from preweaning mortality is somewhat higher in Puerto Rico than in the States, and that it represents a considerable decrease in the efficiency and economy of swine production in the Island.

Around 70 percent of the mortality in this herd was accounted for by pigs born dead or weak. This shows the need of adequate nutrition of the sow during the gestation period. The use of balanced rations, or of rations containing sufficient of the necessary nutrients, is essential during that period. Special care and attention should be given to the litter during the first 2 weeks after farrowing because most of the losses occur within that period.

Losses of pigs killed by the sows can be reduced sharply by the use of guard rails in the farrowing pen.

Scours, which is an important cause of preweaning mortality, can be prevented by keeping the pigs in dry, warm quarters and by the appropriate feeding of the sow.

Although anemia as a cause of death was of minor importance in this study, it is probably of more importance in the Island as a whole. Hamilton, et al. (8), reported that brushing the udders of the sows with a dilute aqueous solution containing iron, copper, and sirup, or iron and sirup, or iron alone, one or more times daily from farrowing until weaning time, completely prevented anemia in suckling pigs. This udder treatment for the first 4 weeks, followed by allowing the little pigs access to a palatable feed mixture containing 0.1 percent of added ferric sulfate, is an alternative method which seems to be just as efficient as is the udder treatment for the entire 8 weeks.

It has been shown that crossbred litters are generally more vigorous and have lower mortality than purebred litters. In Puerto Rico, where the present need is rather for quantity than for quality of production, crossbreeding could be used to promote swine production. Some reduction in the mortality is also to be expected from use of this system of breeding.

Four-year-old sows, or older sows, should not be kept in the herd unless of good value as breeders. In general, sows should not be kept after their fifth litter is obtained.

The great importance of farrowing weight in relation to subsequent mortality only emphasizes the need for the proper nutrition of the sow during the gestation period.

Pigs in litters of eight or more apparently have more chance of dying than those in litters of eight or less. It is possible that artificial feeding may be the best means of reducing the preweaning mortality. It could be used on the excess pigs in a litter or on the whole litter, as the sole method of feeding

the pigs, or only as a supplemental method. A complete study of this procedure should be made.

A combination of the proper breeding, care, and management of the herd is thus essential for the reduction of heavy losses occurring during the preweaning period. Careful attention to these phases of swine raising can considerably improve the efficiency and economy of production.

SUMMARY

The preweaning mortality of 382 litters, comprising 3,841 pigs from different purebred and crossbred sows, was studied.

The average mortality was 35.7 percent. Around 70 percent of the deaths were attributable to still-born pigs or to weak ones that died within the first week after farrowing. Congenital weakness was outstanding among the causes of death.

Some factors influencing preweaning mortality were considered. Summer-born pigs had lower mortality than pigs born in other seasons of the year. Crossbred pigs had lower mortality than purebred. Litters from sows 16 to 23 months old had lower mortality than litters from older sows. Second litters were similarly more vigorous than succeeding litters. Farrowing weight was found to exert an important influence on preweaning mortality; fewer of the heavier pigs died. Litters of 12 or more pigs had higher mortality than smaller litters.

The interrelationship of age, litter number, farrowing weight, and litter size was studied statistically. Age and litter number influenced preweaning mortality mainly through their effect on the litter size, and the litter size through its relation to farrowing weight. Farrowing weight exerted relatively the most important direct effect on mortality.

Some recommendations are made for the reduction of the preweaning mortality:

(1) Using balanced rations during the gestation period of sows; (2) giving special care and attention to the litter during the first 2 weeks after farrowing; (3) using guard rails in the farrowing pen; (4) keeping pigs in dry, warm quarters; (5) reducing anemia by udder treatment with solution containing iron; (6) producing crossbred litters, if possible; (7) culling sows after their fifth litter or after their fourth year of age.

RESUMEN

Este trabajo incluye un estudio sobre el por ciento de mortandad, antes del destete, de 382 lechigadas. Estas sumaron 3,841 cerditos, hijos de diferentes cerdas cruzadas y de pura raza.

El por ciento de mortandad promedio fué 35.7. Cerca del 70 por ciento de los casos de muerte comprendió los animales nati-muertos y los que

nacieron muy débiles y que murieron durante la primera semana. La debilidad congénita fué una de las causas más destacadas de la muerte de los cerditos.

Se consideraron algunos factores que influyeron sobre el por ciento de mortandad antes del destete. Los cerditos nacidos durante el verano tuvieron una mortandad más baja que los nacidos en otras estaciones del año; los cruzados también tuvieron una mortandad más baja que los de pura raza. La mortandad en las lechigadas de cerdas de 16 a 23 meses de edad fué más baja que las de las de cerdas de mayor edad. Las segundas lechigadas fueron más vigorosas que las de los partos sucesivos. El peso de los cerditos al tiempo de su nacimiento influyó grandemente sobre la mortandad antes del destete; murió un menor número de los cerditos de mayor peso. Las lechigadas de 12 ó más cerditos tuvieron un mayor por ciento de mortandad que las de menor número de cerditos.

Se estudió estadísticamente la relación entre la edad, el número de cerditos en la lechigada, el peso al nacer y el número de lechigadas. La edad y el número de lechigadas influyó sobre el por ciento de mortandad antes del destete principalmente, a través de su efecto sobre el tamaño de la lechigada, y éste a la vez a través de la relación con el peso al nacer. Relativamente, el peso al nacer fué el factor más importante, influyendo así más directamente sobre el por ciento de mortandad.

A continuación se hacen algunas recomendaciones para reducir la mortandad antes del destete:

(1) Usense raciones balanceadas durante el período de gestación de las cerdas. (2) Provéanse atención y cuidado especial a las lechigadas durante las dos primeras semanas. (3) Usense cercas protectoras en donde se alojen los cerditos. (4) Los corrales donde se alojen los cerditos deben estar secos y relativamente calientes. (5) Redúzcase la anemia por medio del tratamiento de la ubre de la cerda con una solución que contenga hierro. (6) Si es posible, las lechigadas deben ser cruzadas. (7) Elimínense las cerdas paridoras después que tengan 4 años o 5 pariciones.

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